western union

Technical Review

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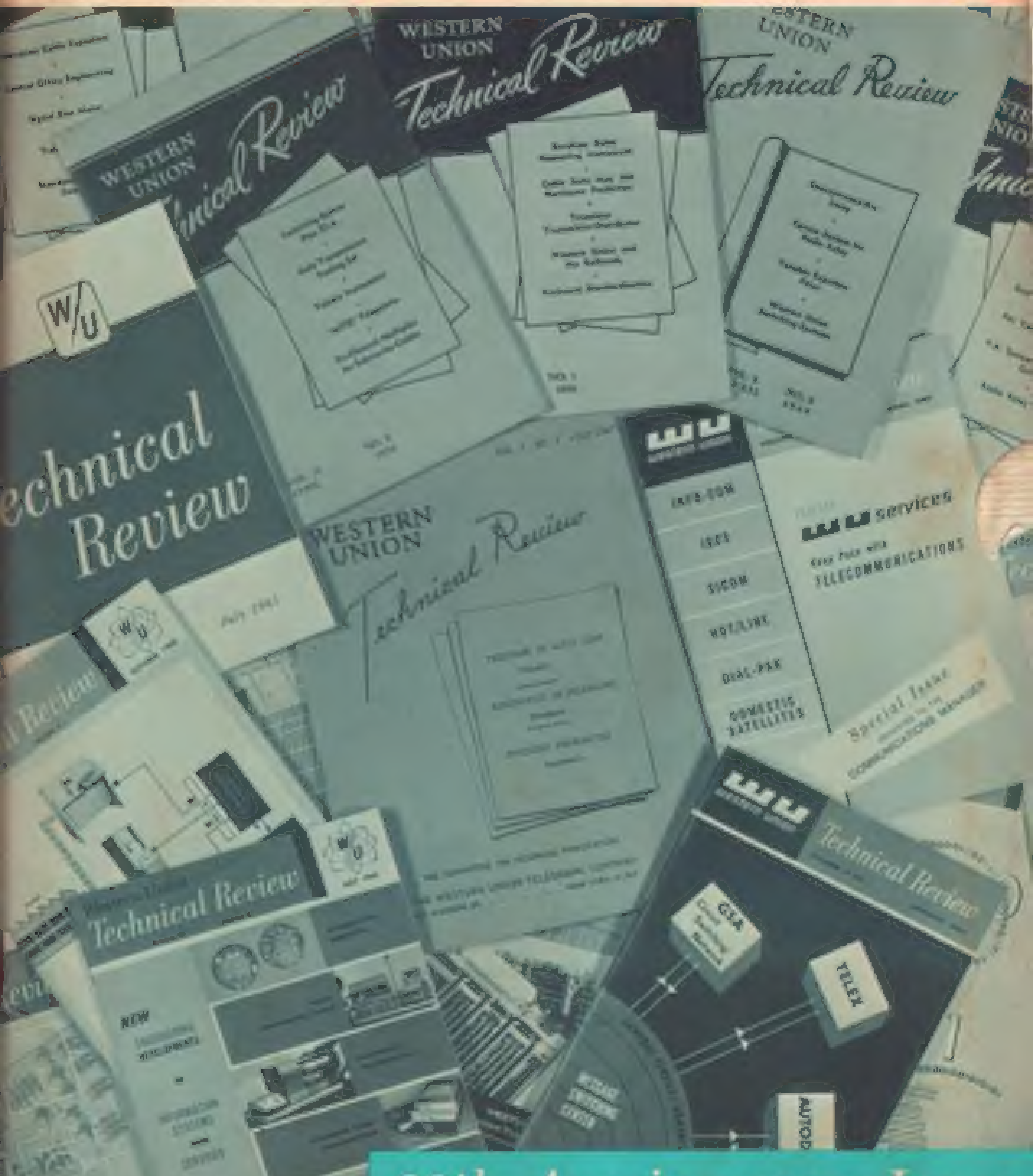
20th Anniversary Issue

western union

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Cover: A montage of many of the covers of the TECHNICAL REVIEW surround the center cover, which is the first cover published just 20 years ago.

Printed in U.S.A.

On Our 20th Anniversary We Resolve

W. H. Fisher
Chairman

The twentieth anniversary of the TECHNICAL REVIEW pays tribute to such a small part of the time Western Union has served the telecommunications industry. But in terms of technical change in Western Union's engineering capability this short interval is immensely significant. The changes in this period from 1947 to 1967 have kept pace with new communications systems and services in all its pertinent phases and in some respects these changes have led the field. The TECHNICAL REVIEW has faithfully recorded this progress in all significant areas by documenting it with articles written by the people who contributed to the progressive steps.

W. H. Watts

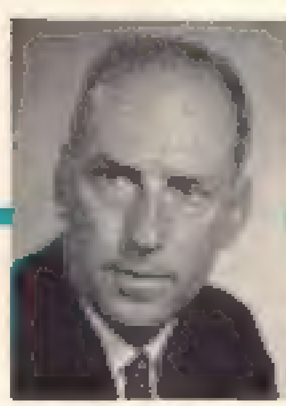
These articles were assembled by a small and devoted cadre of people who for many years shouldered this task in addition to other significant responsibilities. With the increase in complexity accompanying the progress in the telegraph art the work load became too much for the time budget that had been effective for many years. An editor was therefore provided; and under her capable supervision the TECHNICAL REVIEW is now in a position to keep pace with the constantly accelerating progress that it must endeavor to faithfully record. The Committee on Technical Publication feels that they can be justifiably proud of the job that has been done for those first significant twenty years and are resolved that this standard of performance will be continually improved.

G. W. Gamble

At this time we do honor to those responsible for starting the publication and to the First Chairman of the Committee on Technical Publication, Mr. P. J. Howe, who has returned to our new publication offices in Mahwah, N. J. today.

AUGUST 11, 1967 COMMITTEE ON TECHNICAL PUBLICATION

B. Rider



J. H. Booth

M. R. Marsh

C. G. Smith

to honor

P. J. Howe
The First Chairman
of the
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microwave radio— backbone of W. U. transmission system

by R. E. Greenquist

"Two Thousand Telegrams Per Minute By Microwave" by J. Z. Millar was the title of the first article in the first issue of the TECHNICAL REVIEW twenty years ago. It told of "highly successful experiments culminating in the regular daily transmission of commercial telegrams over a microwave system during the past several months." Thus the TECHNICAL REVIEW, in its first issue reported the inauguration of commercial communications in this country via microwave radio.

While the TECHNICAL REVIEW celebrates its twentieth anniversary, Radio Engineering celebrates twenty years of commercial data communications via microwave radio by contributing, to this 20th Anniversary issue, four technical papers that reflect the future of microwave radio communications at Western Union. These four papers touch on satellites, solid state microwave radio equipment, digitized video and multimegabit data transmission via microwave radio. In this preface to these four articles we look back at what the future appeared to be twenty years ago, as seen through Colonel Millar's article, and what has come to pass in microwave radio in Western Union since that time.

We start by asking how advanced was the 1947 microwave radio and where do today's systems stand with respect to advanced techniques. The 1947 system was the first commercial microwave radio and, from that point of view, must be considered advanced. It carried a full data load, in competition with data services carried on the cable facilities of other common carriers, for more than fifteen years. In fact, the microwave radio systems that followed were generally restricted to voice loading or video and it was well over a decade later before others were successful in carrying data on microwave radio. Today, that early equipment is in the Smithsonian Institute and in its place the Transcontinental Microwave Radio System was installed in the early 1960's. Western Union will soon put into operation a new solid state trunk microwave radio network and we are seeking authorization to construct and operate a Domestic Satellite Radio Network in keeping with the current advances in radio transmission technology.

A comparison, of the capacity of the 1947 microwave radio with the capacity of systems today, affords us one of the most dramatic examples of the ability of the technology to respond to growth requirements in an almost elastic manner. The 1947 microwave radio was designed to carry 512 telegraph channels, or 32 voice channels, with half of this capacity "reserved for alternate route transmission." Thus, a capacity of 16 data loaded voice channels was the nominal capacity of the microwave radio then and additional requirements were to "be provided by the establishment of additional beam systems." At that time, this capacity was more than adequate and, even ten years later, the microwave radio installed had a design capacity of only 48 data loaded voice channels. The requirements for broad-

Bob Greenquist, Manager of Radio Engineering has been responsible for the development of microwave radio techniques over the past 20 years and has directed the projects documented in this issue.

PROPOSED WESTERN UNION RADIO RELAY SYSTEM
WITH
SUPPLEMENTARY TRUNK FACILITIES

band data channels had not yet been generated. Now, in 1967 we have microwave radio with capacities up to 1200 voice channels, and with 1800 channels under test, and the limitation is no longer the technology, but regulatory, in that the FCC restricts the emission bandwidth on microwave radio systems.

Traffic, in 1947, was 65 to 75 wpm teleprinters, the high speed data systems of their day operating at rates up to 57 bauds. Our microwave radio now carries traffic spanning the entire spectrum of communications from teleprinter, voice, facsimile, broadband data, special video through time division multiplexed data at rates up to 40,000,000 bits per second.

When the 1947 microwave radio went into operation, it was necessarily the most extensive system in operation. Today, Western Union and AT&T operate the largest common carrier microwave radio systems and the only transcontinental systems. While the Western Union systems are basically data loaded, the AT&T systems are basically voice and video loaded.

A map, of the then Proposed W.U. Radio Relay System with supplementary Trunk Facilities, taken from Colonel Millar's 1947 article is shown above. It is interesting to note that this map represents an almost uncanny prediction of the routes and configurations that microwave radio has followed in the last two decades. If a map of our present systems were superimposed in the 1947 map, it would coincide exactly. Only the new proposed Southern Extension is needed to fill out all routes proposed in 1947, with the single exception of a loop from Chicago through Minneapolis to Omaha.

The microwave radio of twenty years ago served only a small section of the country and land line carrier continued as the basic transmission facility. Today, microwave radio spans the continent and is the "backbone" transmission facility of Western Union's communication plant. How important microwave radio has become to Western Union in the past twenty years can best be understood when we realize that the microwave radio plant, alone, represents approximately one-eighth the gross plant, not including construction.

The past twenty years have borne out Colonel Millar's opening sentence that "One of the most revolutionary advances in telegraph engineering is the application of super-high-frequency radio methods to the transmission of Western Union messages." ■

analog and digital transmission capability of microwave systems

by E. H. Mueller, D. J. Liu and M. Sheldon

Western Union operates over 10,000 route miles of microwave radio as a transcontinental common carrier network. It is the second largest microwave radio network in the United States. The capacity of the network varies from 40 Frequency Division Multiplexed voice channels, on the low density tributaries to 1200 FDM voice channels on the high density trunks. The 40 megabit/second Time Division Multiplexed (TDM) video and data are used on special dedicated systems. It is significant to note that the bulk of Western Union traffic is carried most efficiently on these systems, in spite of the demand for new common carrier services brought about by the "information explosion."

Western Union's present microwave radio systems were designed for analog transmission; that is, even though the systems were loaded heavily with digital signals, the complex FDM signal was transmitted on an analog basis. Thus, the systems were tested for their ability to carry analog signals. These systems were rated on the quantity and quality of the voice channels transmitted or on the fidelity of a television picture. The various parameters of system design were selected to provide the greatest FDM voice channel capacity consistant with a standard of quality. Each system was "tailored" to balance the various noise contributions so as to optimize the performance and reliability characteristics within the design restrictions. Analog transmission was the controlling factor; therefore it was necessary to provide a linear baseband, with flat amplitude and group delay, across the useful transmission spectrum. Each system was restricted by the established bandwidth of the particular microwave radio channel used and by the Federal Communication Commission's limitations upon radiated power.

ED MUELLER (in center of photo to the right) supervises the microwave systems engineering efforts of the transmission group. D. J. Liu (left) and M. Sheldon (right) assist Mr. Mueller in this effort.

The RF bandwidth of the widest channel used by Western Union is 30 MHz. However, 50 MHz RF bandwidth is available in the 11 GHz common carrier band. The significant fact that the complex FDM signal is transmitted on an analog basis subjects it to the consequent intermodulation distortion. The performance of any FDM channel is then dependent upon the loading of the other channels. System loading practices determine the quality of service. These limitations control the ultimate extent of system performance.

The overwhelming increase in data transmission requirements and the rapid improvements in digital techniques, coupled with the number of specific re-

quests for megabit rate transmission require Western Union to re-evaluate the systems in terms of future digital requirements. A study is now underway to determine the digital capability of existing microwave systems and to provide the necessary engineering to utilize this capability in the future.

Radio system parameters vary for either optimum analog or digital operation. A variety of fixed and variable factors control the overall performance. The capacity, quality, reliability, maintainability and the necessary flexibility of operation are all factors in the selection of a system design. There are advantages and disadvantages to both analog and digital transmission. Some of the characteristics of each type of transmission are reviewed in this article.

Transmission Characteristics

The transmission characteristics of microwave systems manifest themselves in the baseband but are the result of noise and distortion contributed from all parts of the system. Transmission non-linearities have many forms, each having specific deleterious effects upon the transmitted signal.

a) Noise

Noise in the baseband of a microwave system may be one of two types: 1) noise that is present when no information is transmitted and 2) noise that is a function of the transmitted information. The first is intrinsic noise. The second is caused by non-linear elements in the system and is referred to as intermodulation noise.

Intrinsic noise is a basic limitation in all systems, and arises primarily from thermal agitation and from noise produced in equipment. Thermal noise is known to have a constant power spectrum. Its amplitude at any instant can be represented by the familiar Gaussian probability density function.

The other factor in determining carrier-to-noise ratio is the strength of the RF signal at the receiver input. This, in turn, depends on transmitted power, propagation conditions, and antenna gains. In considering baseband characteristics, however, it is the relationship between carrier-to-noise ratio at the input and baseband noise, which is important

In frequency or phase modulation, FM or PM, the peak phase deviation, in radi,-ans, is called the index of modulation. In PM, this index is independent of the modulating frequency; while in FM, it is inversely proportional to the modulating frequency.

When flat random noise at RF is translated to baseband in the PM case, the per cycle baseband noise, C_{PM}, at frequency f_1 is expressed as

$$C_{PM} = \frac{a_n\sqrt{2}}{A_c}$$

Where $\frac{a_n}{A_c}$ is the ratio of noise voltage, (in a 1 Hz band), to carrier voltage and C_{PM} is the transfer constant of the PM detector.

In the FM case, the equivalent expression is

$$C_{FM} = \frac{w_1 a_n\sqrt{2}}{A_c}$$

where w_1 refers to the baseband frequency.

Intermodulation noise is the result of phase and amplitude nonlinearities in the RF, IF and baseband sections of the radio equipment, and is included in the following sections on system distortion.

b) Distortion

The major types of distortion and their causes in the wideband microwave systems are:

1. Non-linear amplitude—This may be caused by non-linearities in the modulator, (where the input level variation is changed to a variation in frequency about the carrier) or, in the discriminator, (where the converse process takes place or may be produced by a saturated or overloaded baseband amplifier.

2. Non-constant group delay, corresponding to a Non-linear phase-frequency

characteristic may be produced in baseband filters and amplifiers. Voice channels, used for data, must meet certain delay requirements. For example, Class F switched voice channels must meet the following delay specifications: channels from 1000 to 2600 Hz—less than 165 microseconds; channels from 600 to 2600 Hz—less than 500 microseconds, from 500 to 2800 Hz—less than 1000 microseconds. Most of this delay is produced in the process of deriving the voice channel through the use of multiplex supergroup, group and channel equipment. The radio baseband should not contribute appreciably to the group delay in any of the multiplex subdivisions of the baseband

Non-constant group delay, in IF and RF filters and in modulators and demodulators. This produces unwanted phase modulation and distortion in the output. Transmission non-linearities of this type may be grouped according to the type of transmission-frequency characteristic, whether smooth or discontinuous, and whether a low index or high-index modulation system is involved.

3 Transmission-frequency characteristic. If this is smooth, the transmission gain and transmission phase may be represented, as combinations of linear, parabolic, and cubic functions of frequency Let us assume the input signal is:

$$e(t) = A_c \cos[\omega_c t + \phi(t)] \tag{1}$$

where ω_c is the carrier frequency in radians/second, and the normalized transmission characteristic, as a function of frequency is.

$$Y_n(\omega) = [1 + a_1(\omega - \omega_c) + a_2(\omega - \omega_c)^2 + a_3(\omega - \omega_c)^3] \times e^{j[b_1(\omega-\omega_c) + b_2(\omega-\omega_c)^2 + b_3(\omega-\omega_c)^3]} \tag{2}$$

Then, if Y_n is approximated by a truncated power series and a Fourier transform analysis is applied, the output FM signal is:

$$e_2(t) = \sqrt{[1 + P(t)]^2 + [Q(t)]^2} \cos[\omega_c t + \phi(t) + \theta_i(t)] \tag{3}$$

where $\theta_i(t) = \arctan \dfrac{Q(t)}{1 + P(t)}$

and

$$P(t) = a_1\phi'(t) + a_2\phi'^2(t) + b_2\phi''(t) + 3(b_3 + a_1 b_2)\phi'(t)\phi''(t) + a_3[\phi'^3(t) - \phi'''(t)]$$

$$Q(t) = -a_2\phi''(t) + b_2\phi'^2(t) + (b_3 + a_1 b_2)[\phi'^3(t) - \phi'''(t)] - 3a_3\phi'(t)\phi''(t)$$

Equation (3) shows the unwanted amplitude modulation and phase modulation.

4. In demodulation, the amplitude modulation may be suppressed by "limiting" in which case only the unwanted phase modulation produces distortion in the output

Some of the terms arising from the process described can be equalized after demodulation, but the modulation products represent new frequencies. This type of distortion can be reduced only by equalization before the demodulator

5 Phase Distortion is usually defined in terms of envelope delay, where envelope delay is the derivative of the phase characteristic. The principal forms of envelope delay distortion are first order and parabolic

Consider an example of parabolic phase error at a frequency 5 MHz from the carrier to be 0 25 radians. From this information the coefficient b_2 in Equation (2), is obtained as

$$b_2(2 \times 5 \times 10^6)^2 = 0.25 \text{ radians}$$

$$b_2 = \frac{0.25}{(2 \times 5 \times 10^6)^2}$$

Since envelope delay distortion is normally measured, envelope delay is de-

fined as $\frac{d}{dw}\Theta(w)$ in seconds.

However, envelope delay distortion is normally measured.

For example, let us assume that,

$$\theta(\omega) = b_1(\omega - \omega_c) + b_2(\omega - \omega_c)^2$$

and the envelope delay is

$$b_1 + 2b_2(\omega - \omega_c)$$

Here, the distortion is contained in the second term, the first term is merely the linear phase shift or constant envelope delay. Hence, linear envelope delay distortion in nanosecs MHz can be computed from b_2 as:

$$EDD = \frac{0.25}{(2 \times 6 \times 10^{6})^2} \times 10^{9} \times 2 \times 10^{6}$$
$$1.6ns/MHz$$

Such linear EDD often arises from parabolic EDD, which is inherent in the band pass characteristics of the RF and IF circuits in FM systems, when the parabolic EDD is not centered exactly on the carrier. This can be shown by taking the distortion term $3b_3(\omega-\omega_c)^2$, and substituting for ω_0 the term $(\omega_0-\Delta\omega)$

Analog Capability

There are, in general, two forms of information: continuous and discrete form, voice or the spoken word requires a continuous transmission to transmit varying tone and inflection. Many physical conditions and their graphical representations require a continuous transmission response. Up to the present time, it has been most advantageous to transmit video and voice intelligence in the analog form.

a) Video

The bandwidth requirements for most video service are well established. For black and white television, the baseband is 4.25 MHz; for high resolution TV signals for closed theater loops the baseband is 10 MHz. The bandwidth occupied by a video signal depends upon the amount of information it contains, that is, the frame rate and fineness of detail. Since picture quality is ultimately judged by the viewer, the degree of impairment from various causes is usually evaluated using subjective criteria. Restricting the bandwidth, or simulating this effect with a low-pass filter, produces a pattern which is no longer crisp, and a picture in which the fine vertical lines are no longer well resolved. Resolution is affected by the absence of the high frequency signal components, necessary for transmission of step changes, and also by the system group delay. This group delay distorts the amplitude and phase of these components so that smearing and ringing at the vertical edges is the result.

In color video, first order envelope delay distortion can produce an effect similar to intermodulation in AM systems in which the gain or phase of the color subcarrier may be affected by the instantaneous value of the luminance, resulting in incorrect reproduction of hue or saturation of the color. These effects are measured as differential gain and differential phase. These are video terms for the nonlinear amplitude and group delay of the transmission system. System noise is a definite factor in performance evaluation since it appears as "snow" in the picture. Microwave system noise, for median signal propagation conditions, is not apparent in the picture. However, during signal fades, the noise rises and the picture becomes snowy for the duration of the fade. System quality is partly determined by the depth of fade required to create apparent snow and by the probable frequency and duration of such fades.

Pre-emphasis can be used in video, as well as message FM systems, to reduce the concentration of noise at the higher baseband frequencies. The pre-emphasis or pre-distortion used, in video systems is different from that used in message sys-

tems. Video systems require minimum of detectable noise in the received video signal. Subjective tests have shown that low frequency noise is much more objectionable than high frequency noise of equal power; and a given amount of noise is more objectionable if concentrated in a narrow band than if spread over a wider band. In message systems, however, a flat spectral distribution of noise is desirable.

b) FDM Channelization

In message transmission using FDM, the baseband is composed of many 4 kHz wide voice channels, each of which may carry voice, facsimile, or data. Transmission non-linearities in the FM system produce distortion, which limits the number of channels carried, and limits the allowable deviation.

In the top voice channel of a non-pre-emphasized FM system, the test tone-to-noise ratio is:

$$\frac{S}{N}\,\mathrm{db} = \frac{P_c}{P_n}\,\mathrm{db} + 20\log\frac{F}{f_1}$$

where Pc is carrier power, Pn is noise power in two frequency bands of the width of a voice channel spaced $\pm f_1$ from the carrier, F is the peak per-channel frequency deviation, and f_1 is the frequency of the top baseband channel.

In practical systems of this type, where bandwidth is not severely limited, the choice of modulation index, or frequency deviation in an FM system, generally represents a compromise between the baseband noise reduction achievable by increasing deviation and the increased distortion products, appearing in the baseband as noise, which accompany increased deviation. Typical values for basebands carrying stacked FDM voice channels are 200 kHz RMS per channel test tone for up to 1200 channels, and 140 kHz rms per channel for heavier loading.

When the baseband consists of stacked FDM voice channels, the problem becomes one of relating the modulation noise to transmission non-linearities. Distortion may be expressed, in terms of the modulating signal, as unwanted phase and frequency modulation. A small parabolic phase characteristic, for example, can be expressed as $2b_2 K \sqrt{(t)} \sqrt{(t)}$ where K is the system constant in radians/volt. This is equivalent to linear envelope delay. In this case, the distortion term is equivalent to the original modulation multiplied by a frequency factor (the derivative of the original modulation), and the noise produced will be worst in the top baseband channel. In a system with a 4 MHz baseband, consisting of 1000 4 kHz voice channels, using FM without pre-emphasis and a peak frequency deviation of 4 MHz, a linear envelope delay distortion of 1 nanosecond/MHz will produce a S/N ratio, in the top channel, of 65 db, psophometrically weighted.

Because the baseband intermodulation and intrinsic noise increases with frequency in FM, basebands containing stacked FDM voice channels are generally subjected to pre and de-emphasis, in order to make the noise more uniform in all channels, rather than penalizing those at the high end of the baseband. The pre-emphasis on an FM system is determined by the parameters of the individual system and usually results in a combination of phase and frequency modulation.

Digital Capability

The transmission requirements of quantized information are different from those requirements for analog information. A pulse code modulation (PCM) FM system is more sensitive to such qualities as, amplitude and phase response and is less sensitive to external interference and intermodulation distortion. It is more efficient to transmit digital data information over a PCM system than it would to transmit voice or television. The analog-to-digital conversion, necessary for voice and television signals, generates bit rate requirements that expand the bandwidth, necessary for transmission. The mix of digital and analog information determines the most efficient transmission method.

a) Criteria for Transmission

When sufficient signal power is available to overcome noise, the channel capacity is limited by the following criteria.

1—**Bandwith Limitations**

In order to suppress the intersymbol interference, the bit rate shall not exceed the following limit

$$C = 2f_1 \log_2 n$$

for multi-level signals, where f_1 is the nominal bandwidth of the data channel and n, the number of signal levels.

2—**Intermodulation**

The bit rate stated above, does not take into consideration any transmission time delay impairment. When the time delay is dependent upon frequency, the signal wave form is distorted. In order to suppress the intersymbol interference, ideally, only that portion of the baseband, where phase delay characteristic is nearly linear with frequency and where amplitude response is nearly flat, should be used in the formula quoted above. It is well known that the impulse response of an ideal low-pass filter has equally spaced axis crossings, except for a central peak. If a real-valued transmittance function, which has skew symmetry about the cutoff frequency f_1, is added to the transmittance of the ideal low-pass filter, the same axis crossings of the impulse response are preserved. Hence, if impulses are applied to such a filter at instants separated by $\frac{1}{2f_1}$ the response to these impulses can be observed independently at these instants. In the case of binary pulse transmission, the average of adjacent values is either 0, ½, or 1. If the response to any regularly spaced impulse train is sampled at instants halfway between adjacent impulses and if the obtained response is only the sum of the two adjacent impulse weights multiplied by a constant independent of all other impulse values, then the levels corresponding to 0, ½, and 1 are anchored at the proper times, and hence, intersymbol interference can be eliminated at the receiving end. When the response to each impulse has zero area for every signaling time interval except its own, the transmitted pulse area is then preserved. A transmittance function which satisfies the first criterion and the second criterion is that of a raised-cosine filter, and a transmittance function which satisfies the third criterion is the truncated x/Sinx function. Comparison of the advantages of the raised-cosine spectrum over others with respect to spacing bias and the intersymbol interference reveals that the objective, for the combined transmission characteristics of our transmitting and receiving filters plus the transmission medium, is that the received pulse should have a raised-cosine shape in the time domain.

b) Digital Noise Criteria

In a digital data transmission system, there are two types of noise, namely, thermal noise and impulse noise.

Thermal noise causes wrong decisions when signals are weak. For the same peak-to-peak signal amplitude and the same amount of thermal noise, multi-level signal is more vulnerable to noise impairment than binary pulses. Hence, in a very practical sense, channel capacity is limited by noise impairment also.

Impulse noise is caused by electrical storms and exposure to other electrical systems. In contrast to thermal noise, as impulse noise is dependent upon the phase of its components, suppression of impulse noise peak relative to signal may be achieved by adjusting the phase of the transmittance Y (f) to cause out-of-phase addition of impulsive components. The effect of this phasing on signal components can be compensated by pre-equalization.

To obtain a better signal-to-noise ratio in the digital system, pre-transmission and post-detection filters are used to obtain effective suppression of the noise in the transmission process. A transmittance function for the receiving filter,

which yields only 0.05db impairment for each type of voice relative to optimum, is.

$$Y_r(f) = \cos^{7/6}\frac{\pi f}{2f_s}$$

where f_s is the signaling rate

A transmittance function of the transmitting filter required, then, is.

$$Y_t(f) = \frac{E_0 \pi f}{f_s \sin\frac{\pi f}{2f_s}}, \qquad f < f_s$$

where E_0 is pulse height

A comment on signaling rate is in order. For full-cosine roll-off, the maximum signaling rate is $2f_1$. In terms of bit rate, the following expression,

$$C = 2f_1 \log_2 n, \qquad n \geq 2, \text{ integer}$$

gives the true Nyquist rate for multi-level signals. Very little has been said about signal-to-noise ratio so far. Shannon's celebrated formula is quoted below for comparison

$$C = B \log_2\left(1 + \frac{S}{N}\right)$$

With intersymbol interference suppressed, the error rate is related to signal-to-noise ratio as follows

$$P_n = \frac{n-1}{n}\left[1 - \operatorname{erf}\left(\frac{A}{2(n-1)\sigma\sqrt{2}}\right)\right]$$

where n is the number of levels, A is the peak to-peak signal amplitude at detector input, and is rms thermal noise. The value of noise power which governs error rate is the average at the output of the receiving filter Some other convenient reference points can also be chosen

A special case of interest is one where $n=2$, then the error rate is:

$$P_2 = \frac{1}{2}\left[1 - \operatorname{erf}\left(\sqrt{\frac{S}{N}}\right)\right]$$

a polar random binary sequence with optimum filtering and the signaling rate numerically equal to the bandwidth

Digitized Signals

Digital transmission of quantized information is direct and simple. However, other forms of communication, such as voice or video, require conversion of the information to the digital form before they can be transmitted It is important to recognize that the transition between analog and digital forms can be complex and inefficient

a. Video

Video signals can be quantized and transmitted in the digital form. The original continuous picture can be sampled in space and quantized in luminance, as in the case of monochrome TV. For color signal, additional information, such as hue and saturation, is transmitted in coded form also. To obtain a TV picture with resolution comparable to that of present commercial monochrome TV, 2.5 (10^5) samples per picture are required. To make the luminance of the received picture look continuous, about 50 to 100 luminance levels are required Hence about 1.5 (10^6) bits per frame or 45(10^6) bits per second are required for monochrome television transmission. Band compression techniques may be employed at the expense of picture quality in some cases.

b. Voice

Consider PCM voice signal transmission through a 4 kHz channel. The band-limited voice signal is sampled 8000 times per second by a sampling gate. The resultant sample passes through a compressor which gives preferential gain to low-level signals and then goes to a coder. The coder expresses the sample amplitude as an x-digit binary number or one of 2^x different possible levels. The x-digit code followed by a time slot, which carries supervisory signaling for the channel, is then transmitted. A number of samples

(same as number of channels) form a frame and a time slot is assigned to permit framing the two ends of the system. At the receiving end, the pulses are sorted out and directed to a decoder. The decoder output passes through an expander. A low-pass filter accepts and integrates the expander output to yield the original voice signal.

c. Facsimile

PCM is readily applicable to facsimile. Though the system is similar, the number of luminance levels required is less than that for television transmission.

d. Data (Telegraph, Computer, etc.)

Telegraph and computer data signals are digital in nature. A common baseband may be available to a number of channels through time-division multiplex (TDM). Access to computers may be on time-sharing basis through the use of logics and buffer memories, etc.

e. Time Division Multiplex

Time division multiplex operates on the principle of time sharing. It consists essentially of clock and gates. The sampled contribution of each signal is assembled into a composite sequence of samples each fitting into its time segment of the scanning period, each signal sharing the total time in proportion to its information rate. The extremely high data rate of the multiplexed signals demands that the time division multiplex equipment be designed to operate in the megahertz range. Integrated circuits have been used successfully at these high speeds and help to reduce the cost of this complex system.

System Performance

The ultimate quality of a data channel is rated in terms of its error rate. To obtain a low error rate, the bandwidth should be wide enough to allow shaping in order to suppress the intersymbol interference. The time delay characteristics and the amplitude response characteristics of the channel should be equalized or compensated so as not to alter the raised-cosine spectrum. With all transmission impairments suppressed or compensated, the error rate is a function of the signal-to-noise ratio and the number of signal levels. Table I illustrates this point. In this table S/N is the ratio of the average signal power to the average white Gaussian noise power in a Nyquist bandwidth (fs/2).

Error Rate

In microwave transmission, fading causes S/N ratio degradation and hence affects error rate. To maintain a certain error rate, the allowed margin in db should be added to the required S/N ratio contained in Table I.

TABLE I

Signal-to-Noise Requirements Necessary to achieve a Bit Rate of 10-[illegible]

No. of Discrete Levels of Signal	Type of System: Polar Baseband	FM	PM
2	[illegible]4 db	[illegible]7 db	9.3 db
4	16.3	21.1	13.7 "
8	24.3	26.3 "	[illegible]9.5 "

In a multi hop case, the accumulated noise in the long transmission system may be great enough to prohibit errorless transmission. Regenerative repeaters inserted at some intermediate points in the transmission system would re-establish a high S/N ratio and reduce the additive noise. Sampling for regeneration may be performed near the center of each pulse interval of the received signal by means of a local clock. This clock may be slaved to the long time average of the signal transitions in a synchronous binary pulse transmission system. A complete regenerative repeater should have both capabilities of reshaping and retiming. When equipped with complete regenerative repeaters, time jitter and pulse distortion due to transmission impairments on each individual link would no longer be additive from system point of view.

Estimated System Capacity

Within the framework of the established parameters of communications microwave systems and using the variables that will permit optimized performance, it is possible to rate microwave systems on their analog and digital capacities to transmit analog and digital information.

As an example, a modern solid-state heterodyne-type microwave system operating within a 30 MHz channel bandwidth in the 6 GHz common carrier band, has the approximate capability expressed in Table II.

TABLE II
System Capability

Type of Information	Type of System			
	Digital		Analog	
Message	1	46. megabit channel	3	master groups
	6	megabit channels	30	super groups
	28	1.5 megabit channels*	50	groups
	6	50 [illegible] channels		[illegible]
Video		color video channel		color video channel
		high resolution video channel		high resolution video channel

* A time division multiplexing system for 24 voice channels has an approximate bit rate of 1.5 megabits.

* Digital color video channel uses delta modulation, a form of redundancy reduction, to reduce its overall bit rate.

Digital high resolution video channel uses a lower frame rate to reduce the bit rate below the 46 megabit limit.

It can be seen from the preceding approximation that an analog transmission system has a greater capacity for analog voice signals than a digital system and that the digital system degrades an analog video signal to the extent that some redundant information must be removed to reduce the bit rate to within the system limit. When voice or video signals are digitized, the baseband bandwidth requirements are expanded to produce less effective transmission capability. The opposite is true of data channel capacity. Digital information, when it is time division multiplexed, is carried more efficiently by the digital system. In the case of 2400 bits/sec data channels, the system capacity is better than 10 times the analog equivalent as carried on FDM voice channels. The digital system does have an operating advantage, in that the signal may be regenerated and that in a TDM system the channel loading does not affect performance. The complexity of a TDM system may be a disadvantage in distribution; however, modern integrated circuit techniques are reducing the cost of TDM equipment.

Practical operating systems are usually required to carry a mix of telegraph, data and voice traffic. The practice has been to convert telegraph and data to analog form before frequency division multiplexing it onto a microwave radio baseband. This practice was practical in the past because the larger part of the load was voice and telegraph. As the data load increases and demands higher speeds, quality and wider bandwidth, it cannot be carried as the favored passenger on a baseband consisting largely of voice channels. The quality of the data channels decreases as the data assumes a larger part of the baseband capacity, or if quality is maintained the channel capacity becomes less. If high quality performance is maintained, there is a point at which it becomes more efficient to convert the analog traffic to digital and use time division multiplexing techniques to load the radio transmission medium. There must obviously be a transition period when compatible TDM and FDM systems interface. The high digital capability of modern microwave facilities will permit the increased efficient use of digital techniques.

Satellites

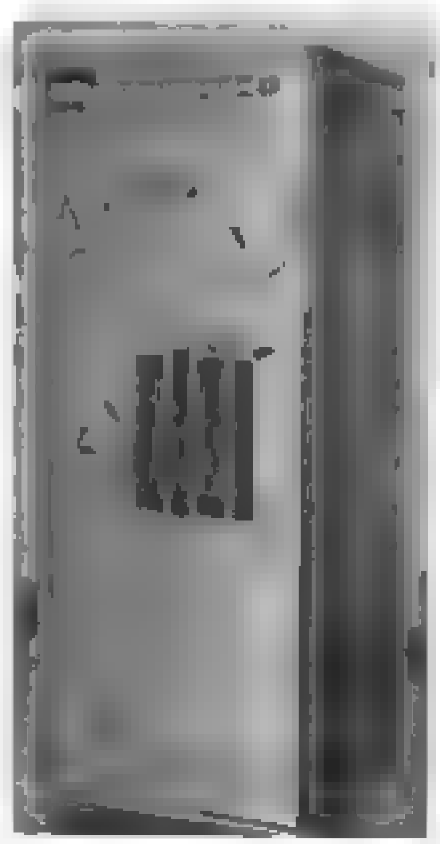
There appears to be a trend to use digital microwave systems for future satellite communication systems, as was proposed recently to the FCC. This plan contemplates wideband satellite microwave systems with 92 megabits/sec capability per channel and depends on digital operation to achieve satisfactory performance under minimal signal-to-noise conditions. The use of higher microwave frequencies, where atmospheric losses are greater, is made feasible by the greater noise tolerance of digital systems. This capability may open up a vast new part of the spectrum to satellite communications and provide many times the present capacity. ■

info—terminal 311

The INFO Terminal 311 was designed as a high speed communication terminal to service 5- and 8-level chad tapes interchangeably. In conjunction with a Western Union Modem, the 311 transmits digital data, which is prepared on off-line teleprinters or other types of business machines, over a voice-band channel to another 311 via the receiving modem or to a computer programmed to simulate a 311.

The transmission is asynchronous and half-duplex at 600 or 1200 baud. Full duplex operation is also available.

Each 311 requires a conditioned 4 kc voice band channel, a voice/data subset and a 1200 baud data set as peripheral equipment. An Automatic Answering Unit 11774-A is required when the patron desires unattended sending or receiving operation.



Special Features

- Services 5- and 8-level tapes interchangeably
- Error detection and correction
- Generates a flag character to identify errors
- Duplicates and or edits tapes off-line
- No code restrictions
- Transmits asynchronously at 1200 baud (600 baud optional)

Optional Features

- Generates block code characters
- Generates even parity on 5-level tape
- Unattended operation
- Operates in half-duplex mode or full-duplex mode
- Domestic service or international DATEL service

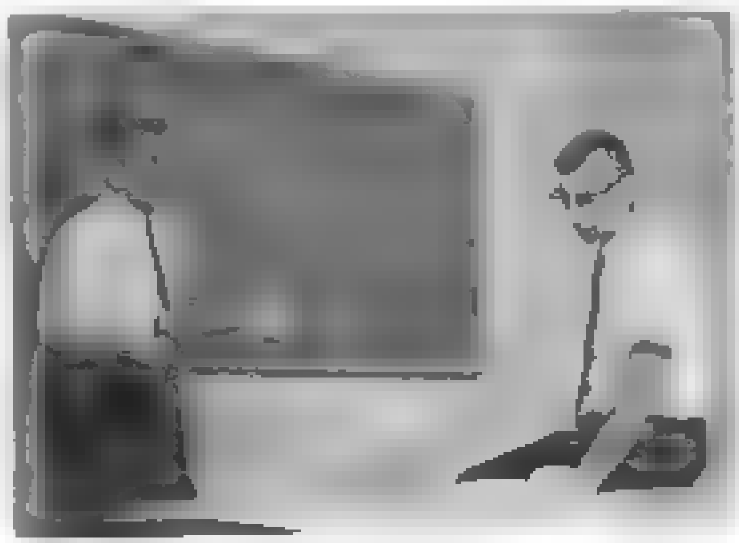
earth stations for satellite communication systems

by E. C. Ottenberg, G. R. MacMichael, and G. W. Johnston

The engineering of satellite earth stations involves compromises between system performance and economics in the traditional manner. However, for common carriers, regulatory constraints are introduced which are a major consideration in system design and affect the technical decisions regarding the performance that can be achieved, and the price which must be paid for that performance. Within the regulatory framework for common carrier satellite systems, the engineering of earth stations is necessarily unimaginative and systems tend to have a "look alike" character. Whether or not these regulatory constraints are warranted in an era of rapidly changing technology is debatable. This article will illustrate the effect of technical and economic factors on the design of common carrier earth stations within the existing regulatory framework.

Western Union has been investigating a method of predicting the performance of a particular satellite system in terms of the various earth station engineering choices. A synchronous satellite system is described here, in the development of the performance prediction, since it is less complex and is preferred for common carrier applications, particularly for domestic common carrier. The performance prediction method is generally applicable to random orbit satellite systems and to differences in the areas of antenna tracking, multiple antenna requirements, antenna noise temperature, receiving system dynamic range, selective fading and interference which will be discussed later.

The three basic assumptions concerning the synchronous satellite system are 1) the use of multiple satellites in synchronous equatorial orbits working to several earth stations, 2) multiple access through a number of transponders in each satellite, and 3) message performance meeting CCIR recommendations.



E. C. Ottenberg is the Supervisor responsible for earth station engineering. He is shown in the picture on the right. George MacMichael (left) has been supporting Mr. Ottenberg in the engineering effort, with Gerard Johnston who is no longer with Western Union. Both Mr. MacMichael and Mr. Johnston have been concerned with system performance and other aspects of satellite systems.

The down link of the satellite system usually controls the system performance. The earth station receiving characteristics are critical in this respect. A review of the earth station receiving characteristics focuses on those technical aspects of the earth station engineering that control subsequent technical decisions in other areas. Thus, a review of the antenna sub-system is necessary prior to the description of system performance calculations, other sub-systems, ancillary facilities and the random orbit satellite differences.

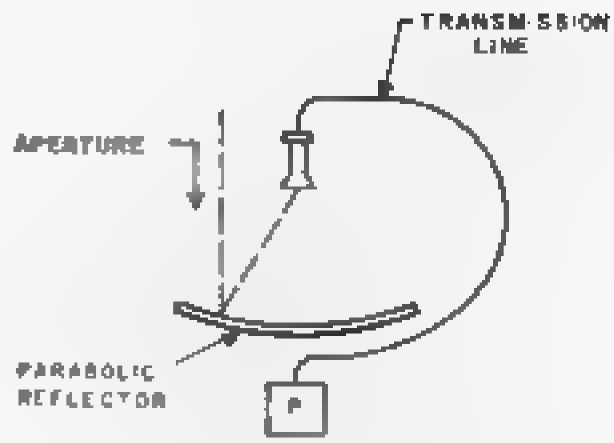


Figure 1 — Parabolic Antenna
(P—is preamplifier)

Antenna Sub-System

The antenna sub-system is the most expensive equipment group in the earth station complex. Due to the great distance between satellite and earth stations, large antenna gains with low noise temperature are required. The antenna requires a tracking mount and an associated control system which contributes to its size, cost and complexity. The size of the antenna sub-system requires a substantial amount of ground to site the earth station. In addition, where more than one antenna is required, additional ground must be provided for the added antenna sub-systems and to keep a minimum spacing between the antennas so they do not interfere with each other.

Types of Earth Station Antennas

Antennas for earth station applications can be selected from a large list of antenna types. These antennas are parabolic with various feed configurations, or horns, or combinations of both.[1]

Four basic types of antennas are of interest. These are the Parabolic antenna, the Cassegrain antenna, the Horn and the Casshorn antenna.

The conventional Parabolic antenna shown in Figure 1, is quite similar to the antennas used in line-of-sight microwave systems. The Parabolic reflector is illuminated by a feed horn located at the focus. This type of antenna is characterized by large side and back lobe power distribution. A principal contributor to undesirable side and back lobes is spillover, energy passing over the edge of the parabola, from the feed horn. In a line-of-sight system, with a spacing of about 25 miles between transmitter and receiver, and with low output transmitter power, this spillover effect does not degrade system performance in terms of antenna noise since the receiver noise temperature, 2610°K for a 10 db NF receiver, masks the antenna noise temperature, which can be as high as 500°K, without degrading system noise. For space communications, however, large transmitter powers are required and spillover of high power distribution to the surface of the earth results in increased noise temperature of the receiving system.

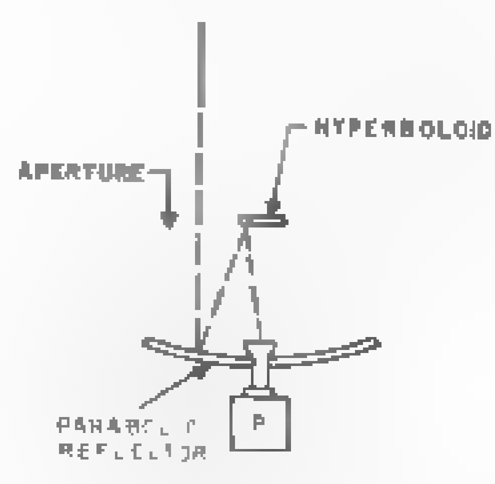


Figure 2—Cassegrain Antenna

The Cassegrain antenna, shown in Figure 2, consists of two reflector elements, the larger one parabolic and the smaller hyperbolic. The major advantage of the Cassegrain antenna over the Parabolic antenna lies in the shorter distance between the antenna and the preamplifier.[1] The feed horn is located at the vertex of the parabolic reflector. The parabolic reflector is illuminated by reflection from the hyperbolic reflector. For large antennas the waveguide run can be 100 feet or more and contribute undesirable attenuation of the signal. The shorter waveguide run in the Cassegrain antenna eliminates additional signal losses which, in effect, reduces the system noise temperature.

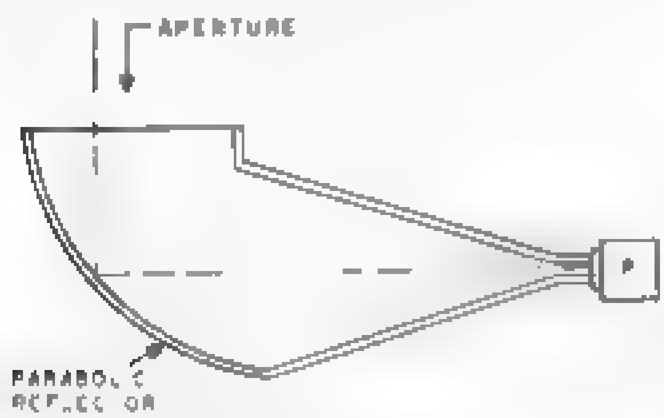


Figure 3—Horn Antenna

The Horn antenna, shown in Figure 3, is theoretically the best for space communications because of its broadband characteristics and low noise properties.[2] However, because it is the largest and heaviest of the antennas, it introduces mechanical problems which translate into electrical problems. Also the tracking mount required is the most complex and costly of all the types considered.

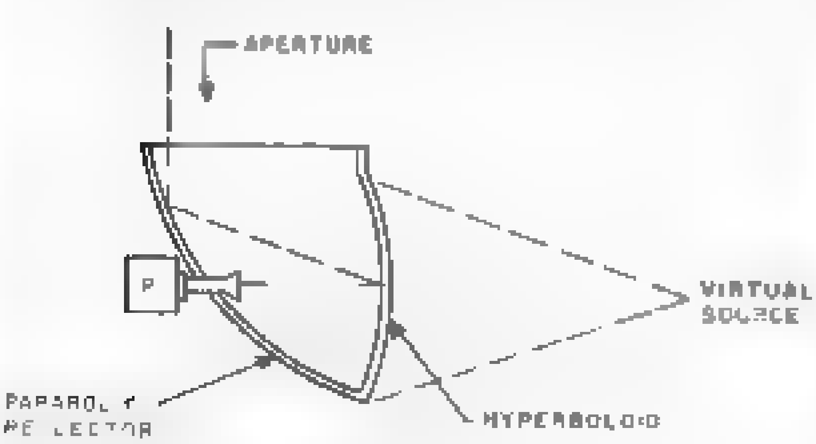


Figure 4(a)—Casshorn Antenna

The Casshorn antenna, shown in Figure 4a, is a folded horn antenna with a feed system similar to that of the Cassegrain antenna. The main parabolic reflector is illuminated by the hyperbolic reflector which in turn is illuminated from the feed horn located at the focus of the hyperboloid. The Casshorn antenna has electrical characteristics which are not quite as good as the Horn antenna. In addition, it is smaller than the horn antenna and has cost advantages in the tracking mount.

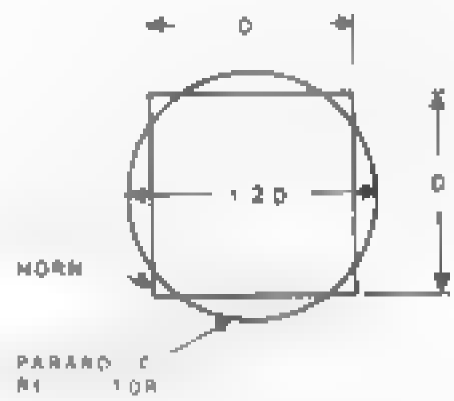


Figure 4(b)—Front View of Aperture Horn vs. Parabolic Antenna

Figure 4(b) shows the relative aperture size for a horn antenna vs. a parabolic antenna for equal gains and typical efficiencies.

Radomes

Experience has shown that radomes, in weather such as rain and snow, can degrade system performance by as much as 9 db.[3] In addition to radome insertion loss additional loss is caused by rain plus rain run-off, or snow plus melted snow run off from the radome. Rain or snow loss is about 4 db, an additional system degradation of about 5 db is evident where radomes are used.

In areas of heavy rain and snow feed heaters or other protection methods may be used in place of the radome. In addition to providing better performance, feed heaters eliminate the cost of the radome structure.

Tracking

The height of orbit of satellite systems places added restrictions on the performance and economics of the system; the higher the orbit the easier the satellite is to track. Because the antenna elevation angles are large, potential interference with terrestrial line-of-sight microwave systems is reduced.

For synchronous satellites, the speed of the tracking system can be relatively slow, because the satellite remains more or less at a fixed point with respect to the antenna axis of the earth station. However, this does not mean that once the antenna is pointing directly at the satellite no further tracking is required. Orbital changes and drifts, however small, do occur. Small antenna beam widths combined with some orbital changes, still require satellite tracking. For earth station antennas working with synchronous satellites, a slow tracking system, having a capability of tracking about 60 degrees in azimuth with a minimum elevation of about 25 degrees, is required for domestic earth stations. Exact ranges are determined by the locations of the satellites.

The principal tracking systems are those denoted as "automatic" and "program-plus-manual" tracking. Automatic tracking systems receive a beacon signal transmitted from an active satellite and use this signal as a means of tracking the satellite. In program plus manual tracking systems, the antenna is steered, usually by a computer, from precise computations of the orbits. In the latter system, a continuous updating of the program is required to account for any orbital drifts. Of the two, automatic tracking is more precise and has the advantage of real time operation. The program plus manual track may be subject to possible operator error. The cost of a slow automatic tracking system, with its advantage of real time operation, versus the cost of a program plus manual track may weigh in favor of the automatic track in working to synchronous satellites.

Noise Sources

Prior to the advance of modern microwave preamplifiers, system performance was limited by the internal noise of the receiver. The use of modern amplifiers, with their inherent low noise temperatures, has drastically reduced the internal noise, so that the antenna noise temperature has now become the major source of noise. Modern amplifiers, such as the parametric and cooled maser types, have noise temperatures of only 50°K and 10°K respectively.

External noise such as that attributed to cosmic sources, add to the effective antenna noise temperature.[4] At the frequencies in question (4GHz), these external noise sources are relatively small, in the order of 16°K at 4 GHz and 25° antenna elevation. The noise associated with atmospheric absorption, for frequencies between 1-10 GHz is small, as there is a "window" in the atmosphere. Atmospheric absorption at 6 GHz and 4 GHz is usually taken to be insignificant for antenna elevations greater than 5°. Noise associated with terrestrial absorption is a function of antenna parameters such as spillover and side and back lobe radiation.

Sun Outage

During the vernal equinox and autumnal equinox the sun, satellite and earth station antenna lay in the same line for several minutes over a period of a few days. At these times, the RF noise generated by the sun will swamp the earth station receiving system and cause a system outage. These periods of outage may be predicted very accurately for a particular location. Some means must then be provided for accommodating traffic during these periods.

Several methods of accommodation are feasible: 1) traffic can be transferred to a spare satellite, if available, 2) terrestrial fallback facilities can be used, or 3) traffic can be stored for subsequent transmission.

Performance Prediction Procedure Criteria

Some of the criteria for determining the predicted performance of satellite earth stations are the following regulatory constraints. These constraints on the technical aspects of any satellite system for domestic communication are prescribed in Part 25 of the FCC Rules and Regulations.[5] These regulations are summarized as follows:

1. On a shared frequency basis, the satellite-to-earth link is specified in the 4 GHz common carrier band, and the earth to-satellite link is specified in the 6 GHz common carrier band. This affects site location due to interference into and from terrestrial systems; satellite transmit power is also affected. [Part 25 202].

2. The earth-to-satellite or up-link Effective Radiated Power (ERP) at 6 GHz is limited to +45 dbW/4kHz in the horizontal plane. This is to limit the interference generated at 6 GHz. This power limit affects the choice of antenna and final power amplifier at the earth station. [Part 25.204]

3. A minimum antenna elevation angle of 5° is required, except under special conditions. However, in a domestic synchronous satellite system, a minimum elevation angle of about 25° is feasible, reducing the interference problem and making it easier to satisfy the limitation on radiation in the horizontal plane required in Part 25 204. [Part 25 05]

4. Satellite ERP is restricted by limiting the power flux density at the earth's surface to −130 dbW/m² for all angles of arrival. In addition, the power flux density at the earth's surface in any 4 kHz slot is limited to −149 dbW/m². The latter is interpreted as requiring some means of modulating the transmitter, when lightly loaded, so as to spread the energy in each 4 kHz slot to 19 db less than an unmodulated carrier at −130 dbW/m². However, the CCIR has proposed a power flux density at the earth's surface in any 4 kHz slot of $\left[-152 + \frac{\theta}{15}\right]$ dbW/m², where θ is the angle of arrival. If the FCC adopts this figure, it may require the lowering of the power in a 4kHz slot to 3 db less than the present FCC rules. This means that the receiving system would require a noise figure 3 db lower, or an antenna with 3 db more gain, in order to provide the same performance. [Part 25 206]

5. Determination of interference from a terrestrial system to a satellite and vice-versa is required and affects site location and, possibly, the choice of antenna, transmitter power and receiver systems. [Part 25 251]

Maximum Received Signal

Using the criteria of Part 25 208 of the FCC rules, maximum received signal at the earth and satellite ERP, is calculated as follows

The gain of an antenna, one meter square at 4 GHz with an efficiency of 55% can be computed from the following equation[6]:

$$G_{db} = 10 \log \left(\frac{4\pi K_e S}{\lambda^2} \right) \qquad (1)$$

where

K_e = antenna efficiency in %
S = antenna area in meters²
λ = wavelength in meters

substituting for these values,

$$G_{db} = 10 \log \left(\frac{4\pi [.55] 1}{[7.5 \times 10^{-2}]^2} \right)$$

$$= 31 db$$

The space loss between two isotropic radiators can be calculated from the following equation[7]:

$$Loss_{db} = 20 \log \lambda - 20 \log d - 22 \qquad (2)$$

where

λ = wavelength in meters
d = distance in meters

For a synchronous satellite in a domestic system, d is about 25,000 miles or 25,000 × 1,609 meters. λ is the wavelength at 4 GHz; .075 meters. Therefore, substituting these values in (2)

$$Loss_{db} = 197 \; db$$

With a power density of −130 dbW/m² being received by an antenna of one square meter with a gain of 31 db, the antenna should see a power density of −161 dbW. The space loss of 197 db added to this, gives a maximum ERP from the satellite of +36 dbW or a receive signal of −161 dbW at the ground

System Parameters

The received signal of −161 dbW, cited above, is extremely low and is limited to this value by regulatory constraint. Adequate system performance requires that high gain antennas and low noise temperature receivers be employed. The uplink, using the same antenna and a high power transmitting tube, can easily produce a reasonable signal at the satellite receiver. Since the down-link, with the lower transmitter power in the satellite, is the more controlling factor, its performance should be calculated first. However, to do this, the following system parameters are assumed

Satellite ERP	36 dbW
Space loss	197 db
CCIR TT/N*	50 db
Pre-emphasis	4 db
Voice channel bandwidth	3.1 kHz
Type of modulation	FM

Figure of Merit

It is convenient to calculate the ratio of the antenna gain (G) to the receiving system noise temperature (T_s), or the G/T_s ratio, for various ratios of top baseband frequency to total baseband rms deviation. The G/T_s ratio is used as a "figure of merit" for an earth station receiving system.

*at top modulating frequency

Noise temperature, T, is a measurement of noise figure, and is expressed as[9]:

$$T = (NF - 1) \; T_o \qquad (3)$$

where

- T · Noise temperature in °K
- NF Noise figure ratio
- T_o 290° K

For a fixed received signal, the greater the antenna gain, the greater the NF or T_s allowable for a given TT/N. A 3 db increase in G, or a 3 db decrease in NF would be equivalent to providing a 3 db increase in received signal or an improvement in the TT/N of 3 db. Therefore, the ratio G/T_s should be as large as possible in order to have the most efficient receiving system. However, doubling the deviation would provide a 6 db increase in received TT/N. G/T_s and deviation are interrelated in determining the TT/N. A review of the Receiving Sub-System, later in this article, will show this interrelationship and indicate how performance versus cost can be traded to achieve a compromise

System Performance

To ascertain the system performance the following equation establishes the relationship among the system parameters.[10]

$$P_n = P_s + 20 \log \left[\frac{f_t}{F} \sqrt{\delta f \, \frac{p_n}{P_c}} \right] \; dbm \; at \; OTL \qquad (4)$$

where

- P_n noise power in dbm at zero test level (OTL) in a voice channel of width δf (Hz)
- P_s total baseband signal power of N voice channels having a top baseband frequency of f_t (Hz), and is (−15 + 10 log N) db.
- F total baseband rms deviation in Hz
- p_n noise power in watts/Hz or KT_s, where K is Boltzman's constant and T_s is the receiving system noise temperature in °K.
- P_c = carrier power in watts or WG, where W is the received signal and G is the antenna gain.

Substituting for p_n, P_s and converting to a log base, for ease of calculation, equation (4) reduces to:

$$P_n = P_s + 20 \log \left[\frac{f_1}{F} \sqrt{\frac{\delta f K T_s}{W G}} \right] \qquad (5)$$

$$P_n = P_s + 20 \log \frac{f_1}{F} + 10 \log \delta f K - 10 \log W + 10 \log \frac{T_s}{G} \qquad (6)$$

when

P_n	43.5 dbm
P_s	16 db
$10 \log \delta f K$	193.5 db
$10 \log W$	161 dbW

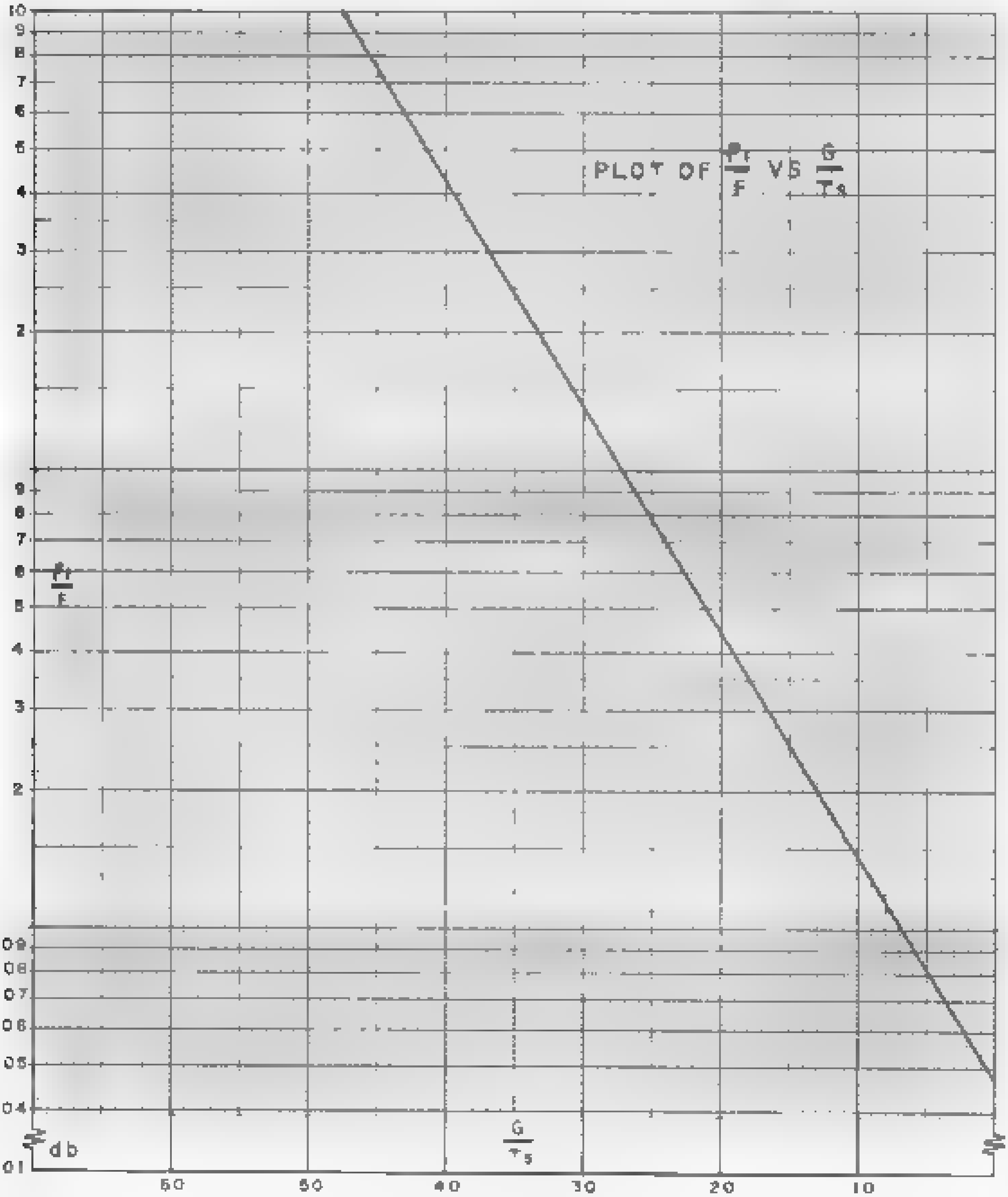


Figure 5—Plot of $\frac{f_1}{F}$ vs $\frac{G}{T_s}$

and these values are substituted in equation (6), the "Figure of Merit" is found from

$$-43.5 = 16 + 20 \log \frac{f_1}{F} + (-193.5)$$

$$- (-161) + 10 \log \frac{T_s}{G}$$

$$10 \log \frac{G}{T_s} = 27 + 20 \log \frac{f_1}{F}$$

In this result, where 10 log G/T_s is the "Figure of Merit," f_1 is the top modulating frequency and F is the total baseband rms deviation. The interrelationship among these parameters determine the TT/N, or the system performance. The ratio f_1/F as a function of G/T_s is plotted in Figure 5.

When this curve is plotted for a specific satellite ERP, space loss, Pn, Ps and δf, it is possible to see the theoretical limits on the receiving system, i.e. for a given system, with a specific top baseband frequency, for every octave change in the baseband rms deviation, the G/T_s ratio will change by 6 db; increasing with decreasing deviation.

Other factors to be considered are fade margin, maintenance margins and line losses. The typical margin for fades (precipitation loss) would be about 4 db. Maintenance margin might well be 3 db. Line losses are included in the effective T_s and will be discussed as part of the receiving sub-system.

A procedure for determining the remaining system parameters once Pn, Ps, p_s, and W are known, follows. Figure 5 can be plotted from equation (6). The received signal is of course, set by the satellite ERP. The receiving system noise temperature is calculated and an antenna gain is selected. For a given G/T_s ratio in Figure 5, the f_1/F ratio may be found. Knowing f_1, the required total baseband rms deviation is obtained.

Additional Constraints

At this point two additional constraints must be considered. An additional limitation on the receiving system is its RF bandwidth. For the previous equations to be valid, the FM receiver must operate above threshold. If the RF Carrier-to-Noise ratio is 10 db minimum, it can be assumed that the receiving system is operating at threshold. Subsequent calculations will show the maximum RF bandwidth allowable. The final limitation is the RF bandwidth required for the selected deviation. This is found using "Carson's Rule."[11] The bandwidth must be less than that required for a 10 db. Carrier-to-Noise ratio.

The transmitting tube requirements fall out from the antenna gain, space loss, and knowledge of the received signal required at the satellite.

Receiving Sub-System

At this time the major limitation in satellite communications is the regulatory restriction on flux density at the earth's surface which limits satellite ERP. Thus, on the down-link path, it is difficult to achieve a good TT/N. Calculations showing a maximum receive signal of −161 dbW were made earlier. It can be seen that extremely low noise microwave preamplifiers working in conjunction with low noise antennas are required to detect these weak signals in the presence of noise. Figure 6 is a block diagram of a typical Receiver sub-system.

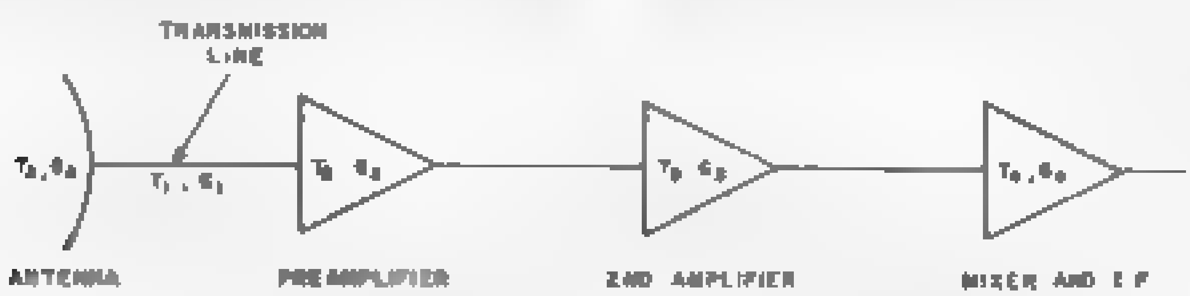


Figure 6—Block Diagram of a Typical Receiving Sub-System

Low noise microwave amplifiers suitable for space communications are masers, parametric amplifiers (paramps) tunnel diodes and TWT amplifiers. For the first stage, where low noise is paramount, masers and paramps (both cooled and uncooled) can be considered. For second stage amplification, where noise temperatures are not as critical, uncooled paramps or tunnel diode amplifiers may be used. Table I lists these amplifier types with their range of noise temperatures and their cost, for an earth station receive frequency of 4 GHz.[11]

Based on system requirements, reliability and economics, various system parameters can be chosen. Antenna and transmission line parameters at 4GHz for a typical system are assumed as follows.

Noise temperature	30°K
Gain	51 db (at 4 GHz)
Assumed transmission line loss	.3 db (G = .933)

The transmission line noise temperature is expressed as[12]:

$$T_1 = T_o\,(LR - 1) \qquad (8)$$

where LR = loss ratio
To = 290°K

Table I

Amplifier Type	Noise Temperature K	Cost in Thousands
Cooled TW Maser	7-13	200-500
Cooled Paramp (4-10°K)	13-22	40-200
Cooled Paramp (20°K)	26-48	40-200
Cooled Paramp (77°K)	56-90	40-100
Uncooled Paramp	120-270	10-50
Tunnel Diode	410-710	1-2

Noise Temperature

The receiving system noise temperature is determined by considering the antenna noise temperature in combination with the amplifier noise temperature, gain and transmission line losses between the antenna and the receiver. The effective system temperature (T_s), using the parameters shown in Figure 6, is:[12]

$$T_s = T_A + T_1 + \frac{T_2}{G_1} + \frac{T_3 + T_4}{G_1G_2 + G_1G_2G_3} \qquad (7)$$

The system noise temperature is calculated so that earth station system "Figure of Merit" may be determined. Once the "Figure of Merit" is determined, and knowing the top baseband frequency, the total baseband rms frequency deviation may be obtained from Figure 5 to meet the CCIR recommendation of a channel TT N ratio of 50 db.

substituting values for LR, which is 1.072 (.3db loss) and for To and solving for T_1, in equation (8), we obtain.

$$T_1 = 290\,[1.072-1]$$

$$T_1 = 20.9°K$$

For the preamplifier stage there are several choices. Based on past performance, reliability, economics and maintainability a typical receiver illustrated in Figure 6 may be composed of the following stages which have electrical characteristics such as

1st Stage — Cooled (77°K) parametric amplifier

Noise temperature 77°K (T_2)

Gain 23 db (G_2 — 200)

2nd Stage — Tunnel diode amplifier

Noise temperature 600°K (T_2)

Gain 17 db ($G_2 = 50$)

3rd Stage — Mixer and I.F.

Noise temperature 5510 K (T_3)

Substituting these values in equation (7)

$$T_s = 30 + 20.9 + \frac{77}{0.933} + \frac{600}{0.933\ (200)} + \frac{5510}{0.933\ (200)\ 50}$$

$$T_s = 137.19\ K$$

The G/T_s ratio, or system "Figure of Merit" is then computed as

$$\frac{G}{T_s} = G_{ANT\ (db)} - 10 \log_{10} T_s\ (°K) \qquad (9)$$

$$= 51 - 21.4$$

$$\frac{G}{T_s} = 29.6\ db$$

For this G/T_s ratio Figure 5 gives an f/F ratio of 1.33. For a top baseband frequency (f) of 5.6 MHz, the total baseband rms frequency deviation (F) is 4.2 MHz. This corresponds to a total baseband peak deviation of 18.9 MHz (4.5 × 4.2) where 4.5 is the peaking factor for the multichannel load[13]. Carson's Rule for minimum RF bandwidth requires that

$$BW = 2\ (\Delta F + f_1) \qquad (10)$$

where f_1 is the top baseband frequency and ΔF is the total baseband peak deviation. Substituting numerical values a minimum RF bandwidth of 49 MHz is obtained.

However all the calculations assume that the FM system is operating above threshold. A "rule-of-thumb" states that an FM system can be designed to operate above threshold when the RF carrier to noise ratio is 10 db. Therefore, for a received signal of −110 dbW (−161 dbW + 51 db), the total noise must be no greater than −120 dbW.

Noise power from (4) is:

P_n — KT_sWatts/Hz

Substituting typical values in the above equation

P_n = 1.38 × 10^{-23} × 138.66 dbW/Hz

= −207.2 dbW/Hz

The total noise power of −120 dbW, is the maximum noise power possible in an RF bandwidth, where the per cycle noise power allowed is −207.2 dbW/Hz. Therefore the RF bandwidth is.

$$RF_{BW} = \log^{-1} (-120 - [-207.2]) \qquad (11)$$

$$= 525\ MHz$$

The limits on the receiver bandwidth are then 49 MHz to 525 MHz. If the receiver bandwidth is set at 50 MHz, the ratio between operating and maximum bandwidth is about 10:1. This gives a noise improvement of 10 db which can be applied to the system performance to account for fade margins due to rain, maintenance margin, and frequency drift.

TRANSMITTING SUB-SYSTEM

The earth station transmitter for the most part is pre-designed; that is, various other requirements, such as satellite and earth station antenna gain, and required satellite received signal have already been selected in the design of the satellite communications system. It then remains to select earth station transmitting equipment (transmitter tube, modulator, etc.), which is capable of transmitting a signal of the required level and transmission characteristics to the satellite.

The transmitter has two major assemblies which are different from those used in line-of-sight systems. The FM modulator assembly, is somewhat more sophisticated in that the earth station FM modulator must handle wider deviations while maintaining the same order of distortion; about 19 MHz for the satellite system versus about 4 MHz for the line-of-sight. The importance of the power amplifier section in the composition of the transmitter requires a more intensive review which follows.

Power Amplifier

The power amplifier consists of a major electrical and mechanical installation which serves to amplify the up-link RF carriers at 6 GHz to high output levels. For earth station power amplifier purposes two types of transmitting tubes are considered[14], klystrons and traveling wave tubes (TWT). Of the two, klystrons provide the higher power gain. Gains of about 50 db are not unusual and the literature indicates the possibility of output levels of 100kW[15]. However, output levels in the neighborhood of 10 kW seem more reasonable and there is evidence of klystrons of the four cavity variety presently in use supplying these 10 kW levels[16].

Traveling Wave Tubes (TWT) are also high power output devices; however, their gains are somewhat less than klystrons. They have the advantage of having much wider bandwidths than klystrons, which is important for high capacity systems and multiple carrier operation. Traveling wave tube gains are in the neighborhood of 40 db and provide output levels of about 1 kW[17].

For the 4 GHz down-link, an antenna was chosen for the earth station receiver which had a gain of 51 db. The same antenna, when used at the higher up-link frequency (6 GHz), has a gain of about 54 db. The satellite antenna has an assumed gain of 20 db at 6 GHz. Calculating from (2) a space loss of —200 db at 6 GHz, and using a satellite received signal of about —90 dbW which is required to permit the use of proven, long life hardware in the satellite, the transmitter output power is determined by using the following equation

$$P_t + G_r - L_s + G_R = P_R \qquad (12)$$

where

P_t Transmitter output power in dbW

G_r Earth station antenna gain at 6 GHz = 54 db

L_s Space loss in db = 200 db

G_R Satellite antenna gain in db at 6 GHz = 20 db

P_R Received signal at the satellite antenna in dbW = −90 dbW

Substituting in (12)

$$P_t = -54 \quad + 200 \quad - 20 \quad - 90$$

$$= +30 \text{ dbW}$$

$$= 1 \text{ kW}$$

In addition to the parameters of gain, power output and bandwidth, there are other applicable requirements which tend to favor selection of a TWT over a klystron. These are phase non-linearity and its associated group delay, phase stability, prevention of spurious harmonic signals and AM to PM conversion.

In addition to the standard 6 and 4 GHz filters which will be in the transmitter and receiver lines respectively, harmonic absorbers, or low pass filters, will probably be required to eliminate 12 GHz from the receiver mixer. The possibility exists that the 6 and 4 GHz filters may be transparent at 12 GHz, and a considerable amount of second harmonic output can be expected from a high power transmitter. This second harmonic, unless absorbed or filtered, could enter the receiver mixer and combine with the receiver local oscillator's third harmonic to give an unwanted intermediate frequency output.

Spreading

In the Performance Prediction Criteria section, the concept of "spreading" was introduced. This requires modulation of the RF carrier with dummy traffic when the system is lightly loaded so that the regulatory limit on power flux density in a 4 kHz slot is not exceeded. One method to accomplish this in a 1200 channel system, loaded with less than 1200 channels, is to install all supergroup and mastergroup filters, with those supergroups which do not have traffic loaded with white noise at the appropriate level. For systems which carry mainly voice, where the loading varies this would, of course, become complex. However, where the load is essentially constant, as in data type loadings, this is a simple straightforward method. Where an RF channel carries video, such as network TV, automatic means of switching from traffic to dummy traffic (which could be a 1200 channel white noise load) can be provided.

Waveguide Arcing

The exact cause of waveguide arcing is not known. However, it typically occurs at power levels above 5 kW at about 2 4 GHz and 1 kW at about GHz. Therefore it is not expected to be a problem using 1 kW at 6 GHz.[18]

Multiple Carrier Operation

One facet of earth station design not previously considered in this article is that synchronous satellites may work with several earth stations. This means that each earth station in the most efficient mode, will transmit and receive several RF carriers each carrier going to or arriving from some other earth station. Each earth station will then require multiple transmitting and receiving systems, or one system which is capable of handling multiple carriers.

When multiple carriers are used, the units selected, such as RF amplifiers, should be the wideband type; capable of handling all available frequencies for economy sake. The problem here is threefold. First, intermodulation in the amplifiers is a problem. Second, wideband front-ends on receiving systems tend to pick up all frequencies, which are in the receive pass band, causing additional intermodulation and or interference. Third, higher power amplifiers are required to handle the multiple carriers. The analysis of this problem is complex.[19]

Interference

The FCC requires the calculation of "coordination contours" for an earth station, to insure interference free operation. Although these rules must be observed it should be pointed out that the FCC has never regulated interference in the common carrier frequency bands for planned route expansion. Western Union, AT&T and other established domestic common carriers have, in effect, regulated themselves by respecting each others' facilities. At the present time, however, the potential interference problem is made more complicated by the more recently established common carriers, which operate earth stations without the traditional voluntary constraints agreed to by the long established domestic common carriers.

Site Selection

In any event, when selecting the location for an earth station, the most obvious choice is near the ultimate traffic destination. The earth station is usually passing traffic into a large population center where terrestrial systems are now operating. In addition, airports are usually nearby, which create additional problems. While these factors and system economics determine the selection of a site, the following basic guidelines should be considered.

1. Locate in a "bowl" where there is natural site shielding, that will aid in reducing interference.

2. Study carefully the locations near airports since an aircraft passing through the antenna beam could cause a problem.

3. Coordinate with other users of the spectrum for most effective use of the available common carrier frequency spectrum.

Boresight Facility and Testing

At earth stations, it has been the practice to provide a permanent boresight facility a few miles from the earth station. This facility is similar to a satellite whose position is absolutely fixed and has a transponder similar to the satellite. This type of facility is used for:

1. Earth station-to-boresight (satellite) to-earth station system tests, run at reduced transmitter power

   Noise Power Ratio (NPR)
   Baseband Intrinsic Noise Ratio (BINR)
   Group Delay
   Linearity
   Deviation
   Spreading

2. Calibration of azimuth and elevation for satellite tracking. This is required even for synchronous satellites as their position will vary somewhat.
3. Possible measurement of antenna pattern and gain.

However, there are various alternatives to a permanent boresight facility. These alternatives are influenced by traffic considerations and economics. The two general categories relate to available system "down-time" and are described here.

It is not normal practice to supply fall-back antennas because of their cost. Where system "down-time" is available, a permanent boresight facility can be installed. System tests are straightforward and the antenna can be calibrated for any mode of tracking. However, where system "down-time" is not available, automatic tracking must be used as the antenna cannot be recalibrated once traffic is placed on the system. Antenna calibration therefore is only a problem when acquiring the satellite, and when switching the antenna from satellite to satellite. Further investigation into ways of solving this initial calibration are required. Three areas which may be fruitful are factory calibration of an automatic tracking system with on site antenna alignment precise enough to receive some signal from the satellite, a portable boresight facility for initial calibration, or the use of radio stars[20] for initial calibration.

Random Orbit Satellite System

The six areas where random orbit satellite systems required modifications to the synchronous systems are the following.

1. Tracking

To guarantee continuous reliable communications, the tracking system of an earth station must ensure that the electrical axis of the antenna, in the direction of the satellite, does not deviate by more than half the antenna beam width. This is a "worst-case" deviation and actual tracking accuracy is specified in the order of several minutes of arc. Speed of tracking places severe limitations on this accuracy. Thus, a low-altitude random orbiting satellite, whose angular velocity changes quite rapidly with respect to the earth station antenna axis, requires a very expensive full steering capability (360 degrees with a minimum elevation of 5°) tracking system.

2. Antennas

To maintain traffic continuity, a random orbit satellite requires at least two antennas at an earth station. The first antenna carries traffic with one satellite while the second antenna acquires a new satellite. Traffic is then "handed-over" from the first to the second satellite before the first one is out of range.

3. Selective Fading

Selective fading, which is present in microwave line-of-sight systems, is not a problem in the synchronous satellite system. However, a random orbit satellite system, which requires handover from one satellite to another, requires consideration of this problem[21]. Even though a satellite may be acquired at the horizon, traffic would most likely not be transferred until the satellite is well above the horizon since selective fading occurs when the signal travels large distances through the lower atmosphere at low elevation angles. Small system margins preclude providing fade margin for selective fading.

4. Receiving System Dynamic Range

A synchronous satellite will always give a fixed space loss to the earth station. A random orbit satellite, depending on its height, produces a maximum space loss when acquired at the horizon and minimum when it passes closest to the earth station. Thus, a random orbit satellite system requires the design of a receiving subsystem which can handle a dynamic range depending upon the random orbit.

5. Antenna Noise Temperature

Acquiring a satellite just above the horizon increases the antenna noise temperature atmosphere at lower elevations.

6. Interference

Since the antenna can track 360° in azimuth and 5° to 90° in elevation, interference can be generated in all directions and at higher levels than when working to a synchronous satellite. This places an added burden on selection of an antenna and site.

Summary

A Performance Prediction method has been presented in this article which may be used to predict satellite system performance as it relates to earth station design. However, high level judgment must be exercised by the system designer as the "numbers" do not take into account the economic and technical compromises which must be made in the earth station design.

Satellite design also affects the earth station design. A 1 KW final power amplifier for the earth station has been used in the discussion. However, this assumed a satellite receiver noise temperature of about 2610°K (10 db NF) and a 20 db gain antenna. If the satellite receiver were equipped with a tunnel diode front end having a receiver noise temperature of 870°K (6 db NF), and the receiving antenna had a 2 db increase in gain, the earth station power amplifier could be reduced to 250 watts. It then might be possible to do away with liquid cooling for the transmitter tube.

Any implementation of a satellite system requires a review of the state-of the-art because of the rapidly changing technology which can drastically affect performance and economics.

ACKNOWLEDGEMENT

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NSD-6 radio system

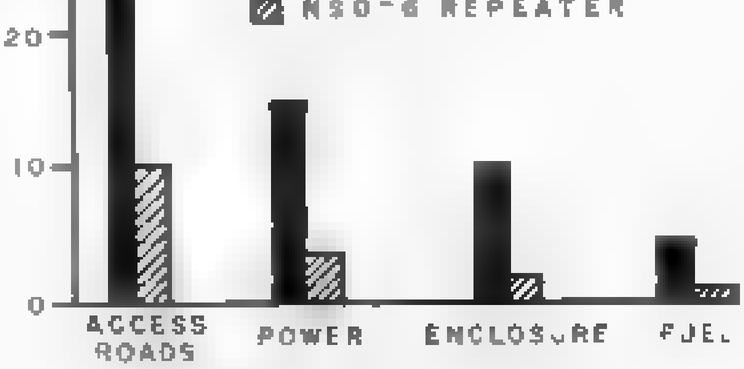
solid state, short-haul microwave

by D. D. Klimek

A modern all solid state microwave radio relay system has been developed for low cost short haul low density tributary systems. The equipment is intended to provide transmission facilities for up to three one and one half megabit TDM channels or 360 FDM voice channels over tributary routes up to 150 miles in length and interconnecting with Western Union's high density transcontinental microwave radio relay systems. This equipment has been named NSD-6 (Narrow Bandwidth, Short Distance—6 GHz).

The NSD-6 radio equipment was developed by Western Union, and manufactured by Microwave Associates Inc. In addition to contributing system engineering concepts, Western Union designed the baseband combiner and fault and order wire system.

An important advantage of the NSD-6 is the minimal support facilities required for a remote installation. This is evident in the accompanying bar graph, which compares the relative costs of the facilities of the NSD-6 with existing systems. The NSD-6 system reduces installation time and lends itself to temporary installations of communication links, which before now were prohibitive because of the high cost of installation. The reductions illustrated in the bar graph are made possible by the type of equipment used in the NSD-6 system.



RELATIVE COST OF
TUBE TYPE REPEATER VS NSD-6 REPEATER

D. KLIMEK provides engineering support for existing and future microwave systems.

Special Features

The main features of the NSD-6 radio equipment are

- Low cost
- 360 voice channel capacity (with noise performance of one hop equal to the CCIR recommendation for a ten-hop trunk system)
- All solid state components
- Low primary power consumption
- Plug-in modular design
- Light weight and small size
- Frequency diversity operation
- Operating temperature range (−30°C to +60°C)

This system was developed primarily to meet the need for a low cost, low density spur or tributary microwave radio system. With a suitable weatherproof cabinet, it can be installed without construction of a building to house the equipment. It provides a transmission channel at a lower cost than conventional systems because of the reduced costs of the support facilities at terminals, and at remote repeater sites. A particular feature of the NSD-6, which contributes to its low cost is its low primary power consumption. The equipment may be operated from thermoelectric generators, thus eliminating the need for commercial power lines, which are expensive in remote areas.

The low power consumption, weatherproof enclosure, small size and light weight greatly reduce the costs for the installation of a station in a remote area. The installation cost of the NSD-6, is minimal because there is no need for building construction, power line construction, high quality access roads and diesel power plants, required for high power tube-type radio systems.

Further cost reduction is realized from mass production of the radio system. It also requires less time to test and install The use of all solid state components improves the reliability, while the plug-in module feature reduces maintenance time by permitting quick replacement of parts.

A major feature of the NSD-6 system is that it can be used at frequencies that are interleaved with the normal CCIR RF channels used in high density trunk systems. This type of operation is made possible, through the use of low transmitter power output and very narrow receiver filters, to prevent interference to or by the high density systems. This makes it possible to route the system through locations that are saturated with high density systems. The interleaving of frequencies with the CCIR channels makes use of that part of the spectrum otherwise used infrequently

Since the NSD-6 is tailored to this plan short routes can be established in congested areas where previously it was necessary to provide extra repeaters to coordinate the system with the established frequency environment of the high density system. The frequency plan of the NSD-6 permits operation of spur and tributary routes out of the trunk route junctions, without using up the CCIR frequencies required along the route of the high density system

The frequency plan of the NSD-6, and its mobility and reduced investment in the cost of equipment and support facilities results in an improvement of our competitive position in providing communication services. The nature of the equipment permits the consideration of remote locations which were not feasible with other systems. Also, the frequency plan permits operation within areas containing heavy route systems.

Operation

The NSD-6 system operates in the 5925-6425 MHz common carrier frequency band. It has a capacity of up to three one and one half megabit TDM channels or 360 FDM voice channels. Western Union uses this system on links which require relatively few hops. It is also capable of satisfactory performance on a radio link of ten hops, where the distances between stations may be fifteen to thirty miles.

The NSD-6 is a remodulating system, permitting the addition, dropping or straight through operation of baseband

circuits at any repeater along the radio link. Because the signal is brought down to baseband at each repeater, an important parameter of the system is the stability of the modulator sensitivity and the receiver output level. The stability of a single transmitter-receiver combination must be kept to a tight tolerance in order to provide acceptable performance over a reasonable number of hops. This baseband stability is obtained, by keeping the baseband level within ± 0.25 db over the specified temperature range and expected primary voltage variations, and by using modulators and receivers with opposite temperature characteristics to compensate for level changes.

Solid state components, operated well below the manufacturers recommended ratings provide excellent system reliability. Solid state components are used for all active devices, but the circuits are designed so that the passive elements determine the performance of the system. In this way variations in the active devices have little effect on circuit performance. This type of design is more reliable and maintenance free than vacuum tube-type designs which require circuit retuning as a tube ages or is replaced.

The system has a service life of several years with slight re-tuning of frequency controlling modules at prescribed intervals. However, if a failure should occur, the faulty modules can be easily detected through the use of a test set which monitors nineteen different test points. By taking periodic readings of these test points, the power supply voltages, received signal level, transmitter frequency and power output can be determined. When the failed module is located it can be replaced, without any need of retuning the system. Designing each module to be independent of its associated modules in the system makes replacement a simple task.

To locate a faulty component the maintainer is able to communicate, via the service channel, with a terminal station or any other repeater station to report the status of the equipment at his station.

Components of System

A front view of the prototype model of the NSD-6 is shown in Figure I.

The basic NSD-6 rack contains two transmitters and two receivers, a waveguide branching network, a fault alarm and local order wire (or service channel) system, a combiner, two independent power packs consisting of nickel-cadmium batteries floating across the output of battery chargers operating from commercial power, and inverters that supply all the required voltages to power the system. The dimensions of the basic rack are 48 inches high by 20 inches wide by 12 inches deep. Most of the modules are mounted on the top portion of the door panel. This door panel opens to reveal the transmitter, tunnel diode amplifier, waveguide branching network and the inverters.

The waveguide branching network contains all the filters, isolators, and circulators necessary to use one antenna with two transmitters and two receivers. Because of the miniature circulators, it is possible to mount the entire waveguide network within the upper section of the basic rack. Of particular importance, is the receiver RF filter, which selects the proper RF channel carrier for processing within the receiver. Since it was planned to use the NSD-6 system in areas of existing heavy traffic systems, it was necessary to specify strict tolerances on the passband and temperature stability of the filter. Special receiver RF filters were constructed out of pure invar, because of their excellent temperature characteristics. These filters are used in installations which require high rejection of frequencies adjacent to the operating RF channel.

Despite the miniaturization of the waveguide branching network, its size still limits the minimum dimensions of the basic rack. Further reductions in the size of the branching network, will reduce the size of the rack, since the transmitting and receiving modules are small. An example of the miniaturization in the NSD-6 is illustrated in Figure 2. This is illustrated by observing the number of signal processing functions performed in the trans-

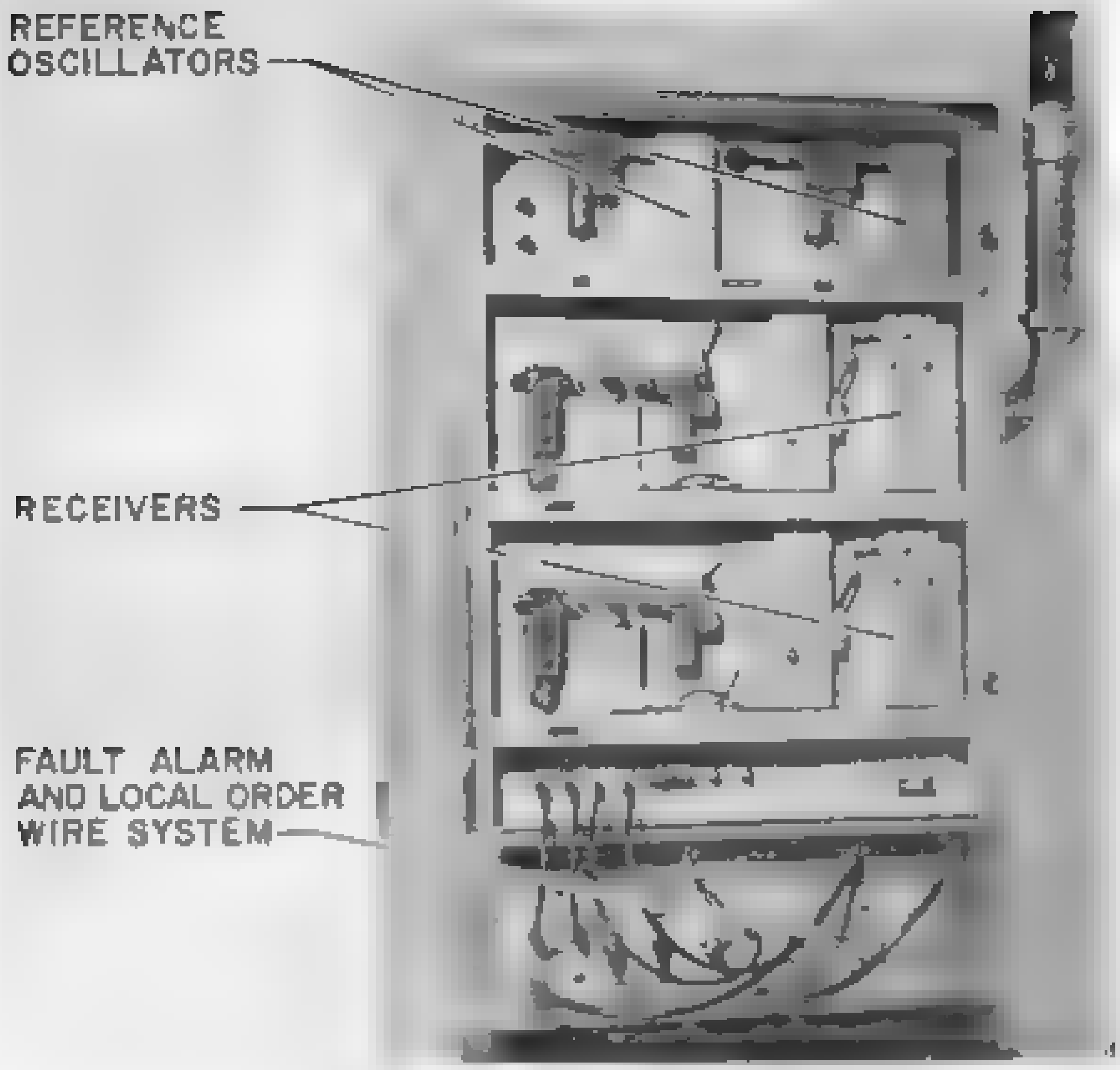


Figure 1 Front View of NSD—6 Rack with Door Closed

mitter module, in Figure 3, and comparing them with the transmitter package of Figure 2, which measures 3 inches by 4 inches. Signal processing in the transmitter encompasses the conversion of the incoming baseband signal to a filtered modulated signal in the 6000 MHz band

As shown in Figure 1, the AFC modules for each transmitter are mounted side by side on the top shelf of the hinged panel The modules for the two receivers are mounted on the next two shelves. Connectors are mounted at the bottom of the panel to provide access to the modulator inputs and the receiver outputs. The baseband combiner and local order wire unit are mounted directly below this panel Primary power is supplied to the system by the nickel-cadmium batteries and the battery chargers which are housed in the compartment at the bottom of the rack

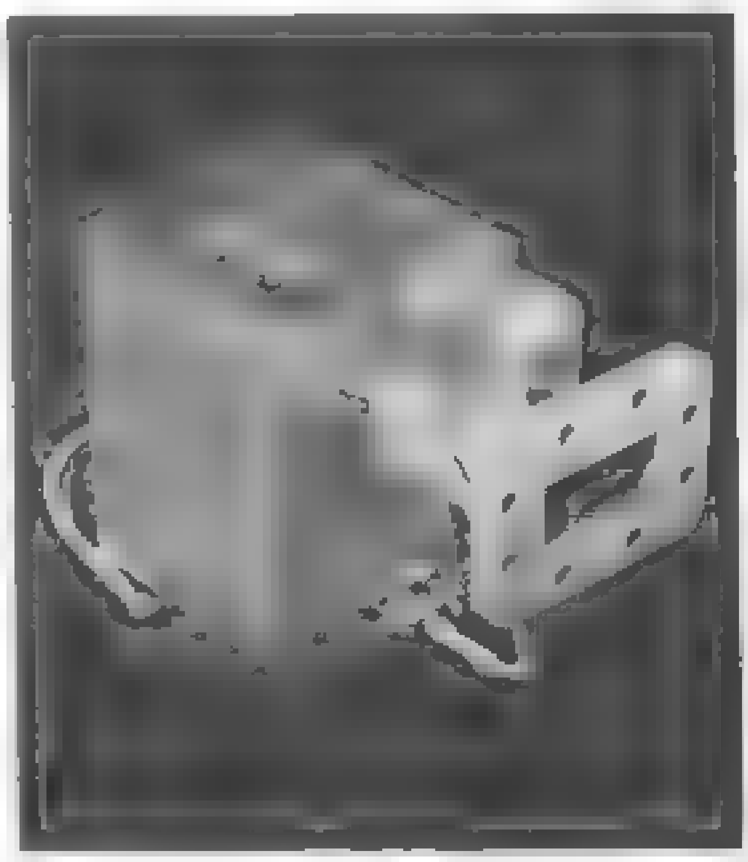


Figure 2 Transmitter Package

Transmitter

A block diagram shown in Figure 3, describes the signal path in the operation of the NSD 6. The incoming baseband signal modulates a 500 MHz varactor tuned oscillator in the transmitter. The modulated signal is passed through a buffer amplifier, a power amplifier and then multiplied to 6000 MHz in a by-twelve step-recovery diode circuit. The low power output of the transmitter (20 mW) practically eliminates interference problems and permits interstitial operation within heavy traffic systems.

The frequency of the transmitter is kept within a tolerance of ±0.03% by an AFC circuit. The output of the transmitter is sampled and mixed with a reference frequency to produce an 80 MHz IF output. Any change in the output signal results in an error voltage being fed back to the 500 MHz oscillator, to correct the transmitter frequency within the prescribed limits.

The reference oscillator, in the AFC system uses a temperature compensated high-Q invar cavity as the frequency controlling element. The tunnel diode in the reference oscillators of the AFC system oscillates directly in the 6000 MHz band. the oscillators maintain a frequency stability of ±0.5 MHz under all operating conditions.

Receiver

A receiver with a low noise figure of 7 db is made possible through the use of a tunnel diode amplifier in the "front end" of the receiver. The amplifier provides 15 db of gain across the 5925 to 6425 MHz band, independent of RF channel frequency. The estimated RF input level to the TDA for a fifteen mile hop system is 55 dbm.

The low power input signal to the mixer permits the use of a low power Tunnel Diode Oscillator as the receive local oscillator. The oscillator used is almost identical to the one used as the reference oscillator in the AFC circuit of the transmitter and is tunable over the entire band. The TDO is unique, in that only a dc power input of 25 mw is required to provide an output of -10 dbm at 6000 MHz. Because of its inherent stability (+0.5 MHz at 6000 MHz), no external frequency control circuitry is required.

Receiver system bandwidth is defined essentially by the 70 MHz IF filter, which has a steep-skirted response with a 3 db bandwidth of 9 MHz. The IF amplifier is a wideband device, whose bandwidth is determined by the IF filter, at its input. The amplifier contains automatic gain control and squelch circuits, permitting operation over a 35 db range.

Service Channel Facilities and Fault System

The NSD-6 requires only one voice channel to monitor faults and provide service channel facilities. The lower part of the voice channel, 300 Hz — 1600 Hz, is used for voice facilities. Fault tones are generated in the upper frequency range, 1840 Hz to 3455 Hz. The advantage of one voice channel bandwidth is realized in the conservation of carrier spectrum space when it is necessary to transmit the service channel and fault conditions from a terminal station to a remote monitoring point.

The fault tones normally signify a "no fault" condition at a station. The status of the radio equipment is determined at the monitoring station. These tones will be disrupted and an alarm sounded when any one of the following changes occur:

1) Decrease in transmitter power
2) Drift in transmitter frequency
3) Decrease in received signal level
4) Decrease in primary voltage, or
5) Decrease in inverter output voltages

At terminal installations where the combiner is used, two additional fault tones are generated to indicate the presence of pilot tones into and out of the baseband combiner.

The fault tones indicate only the condition of the radio equipment. The specific problem can be determined by the test set.

Voice facilities are permanently provided at each terminal. Voice facilities at repeaters are provided by the headset included in the test set.

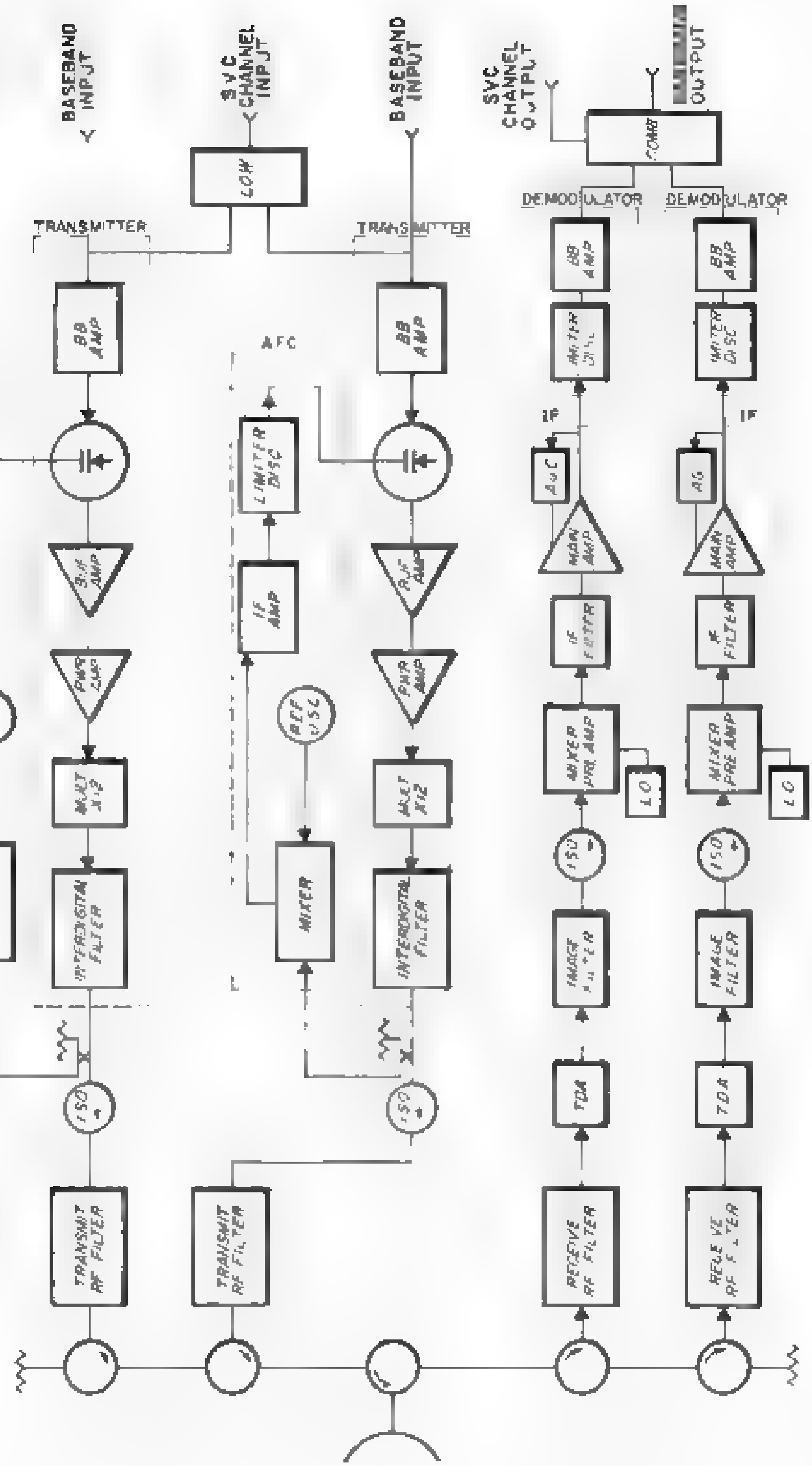


Figure 3 Block Diagram of NSD-6 Radio System

Combiner

The baseband combiner shown to the right in Figure 4, is an all solid state unit designed by Western Union, for use with the NSD-6 radio system. The combiner takes the two outputs from the radio system and provides an output that has a signal to noise ratio that is equivalent to or better than the signal-to-noise ratio of the better radio output. Selection or emphasis of the beam with the best noise performance is obtained by monitoring the noise in a frequency slot just above the baseband. If the two incoming beams have unequal noise levels in the monitoring slot the beam with the higher noise level will be attenuated. A 308 kHz pilot tone on each beam is monitored also to determine the continuity of a path from terminal to terminal. If the 308 kHz tone is absent on one path, the output of the combiner will automatically switch to the path with the pilot tone. The absence of pilot tones on both beams indicates that the generating equipment has failed. Under this condition the combiner will operate in the normal combining mode.

Although primarily designed for use with the NSD-6 radio system, the Baseband Combiner is capable of being operated with the other radio systems, providing a compact package that has low power requirements and high reliability.

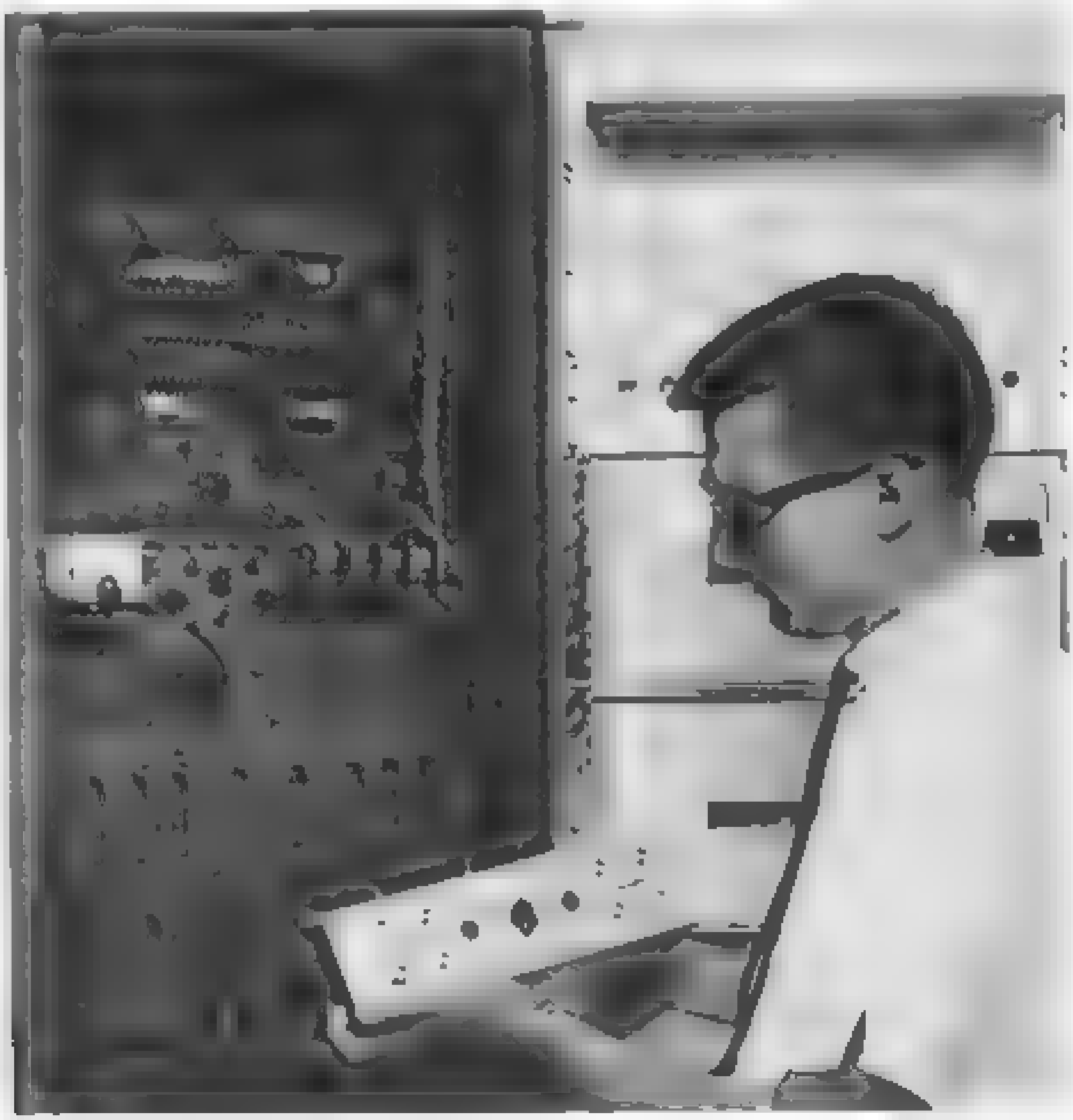


Figure 4 Baseband Combiner held in hand is compared by the author Dan Klimek, to the Baseband Combiner presently used in the Transcontinental Microwave System.

TABLE 1

System	Circuitry	RF Output Power	Voice Channel Capacity	Two-Way Diversity Repeater Power Requirement
WLD-6 (transcontinental)	tube-type	TWT-5 watts	600	3300 W
MLD-4B (tributary)	tube-type	Klystron-5 watts	240	4000 W
CW-60 (tributary)	Solid-State	70 mW	600	250 W
NSD-6 (tributary)	Solid-State	20 mW	360	35 W

Power Source

The low power requirement of the NSD-6 radio system makes it possible to use such power sources as solar cells, fuel cells and thermoelectric generators as primary power. These devices are independent of commercial power lines and can be used in remote area applications

An economical source of power for remote areas is the thermoelectric generator. The thermoelectric generator operates on the principle that a voltage is generated when one junction of two dissimilar metals is hotter than the other junction. This effect, known as the Seebeck effect, is enhanced in the generators on the market today through the use of semiconductor materials. The generator voltage is proportional to the temperature difference between the junctions. The temperature differential is derived from the combustion of some form of fuel. Presently two makes of thermoelectric generators are being tested using propane for the fuel supply of the generator

Thermoelectric generators are operable in high winds, heavy rains and snow, have no moving parts, and are reliable for remote area locations where access to the site may not be possible at certain times of the year

The low dc power requirements of the NSD-6 represents a real breakthrough in repeater systems used by Western Union A comparison of the power requirements of several radio systems presently in use is illustrated in Table 1. These ratings are given in terms of two way diversity repeaters which contain four transmitters and four receivers. The use of solid state units as replacements for the tube type units greatly reduces the power requirements of the system.

Table 1 illustrates the low power requirements of the NSD-6 radio system This low power requirement eliminates the need for power lines and diesel generators, usually required at the repeaters of the radio systems presently used.

Pilot Study—New York to Fair Lawn

An experimental circuit using the NSD 6 radio equipment was operated over a 15 mile communication link between the Computer Laboratory in Fair Lawn, N.J and Western Union Headquarters, New York City. This link provided a convenient means of field testing the NSD-6 equipment under various operating conditions

As a result of the tests system performance was found to exceed design objectives. Factory alignment held exceptionally well and installation was considerably simplified The system lends itself to expansion beyond 360 channels and merits consideration as a primary, medium density, tributary system. The techniques used here can be incorporated in existing and new microwave systems to extend performance and conserve space and power, both in the 6000 MHz band and in other bands and in cross band diversity systems. ■

digitized video transmission over common carrier microwave

by Edwin H. Mueller

The broadcast television signals available today are often transmitted over thousands of miles of cable or microwave radio before they reach local broadcasting stations for distribution. They are presented in real time, except for the very short transmission time; an event is viewed just as it takes place. The picture information is transmitted on an analog basis.

When microwave radio is the medium of transmission, picture quality is affected by the length of the microwave system and the atmospheric conditions along the route. Modern video constantly demands better, more dependable transmission. In the case of military video the Government requests security from interception. Digital transmission techniques can meet all of these requirements. Digital signals can be periodically regenerated permitting long distance transmission without deterioration of signal-to-noise ratio. Digital signals can be encrypted to provide security. In addition other digital information can be carried with the video for reference and control purposes where additional analysis of the video information is required; for example, scientific or military analysis may be a requirement in addition to real time viewing.

The choice between analog and digital transmission is often made as a compromise between economy and system objectives. The purpose of this article is to review the present state of the art. Specific choices should be decided by individual system requirements

Ed Mueller (right) is the Supervisor of Radio Transmission, responsible for the engineering of all radio transmission systems.

Video Signal

The video signal is composed of a series of individual still pictures or frames which depend on the ability of the eye to interpret them as a moving picture, when they are transmitted in sequence. To produce a copy of each picture, the original must be scanned or sampled, one small segment at a time. Each sample produces an electrical current or voltage proportional to the shade or luminance of the picture element being scanned. Picture elements are usually sequentially scanned in horizontal lines, the lines are then scanned vertically to complete the frame

Video signals are usually transmitted in analog form. Thus, the luminance of each successive picture element is represented as a smooth change in electrical intensity as the line is scanned. If the electrical representation is to accurately reproduce the luminance changes, the electrical system must have a bandwidth dependent on the scanning rate and the degree of resolution desired. In color television, the color information must be simultaneously sensed and scanned to produce another electrical signal from the chrominance or color information. Although the luminance is an

analog representation in this case, the video transmission is really digitized in so far as line scanning and frame rates are concerned

Digital Video Signal

In the digitized representation of the luminance of picture elements, the picture is divided into a specific number of discrete horizontal sampling elements as well as vertical scanning lines. Each element is represented digitally as a distinct luminance level It has been found that 64 discrete levels of luminance can adequately reproduce the luminance range in most pictures Each sample then requires 6 bits of information to describe its luminance levels

In a picture that is composed of 500 scanning lines and 500 discrete samples per line, there would be 500 × 500 or 250,000 samples. At 6 bits per sample and a frame rate of 30 frames per second, the digital transmission rate or bit rate for the system is 250,000 × 6 × 30 or 45 megabits per second. To attain an equivalent resolution in an analog representation the required baseband bandwidth should be about 4 5 MHz. When color information is added, the digital bit rate might be as high as 60 megabits second and the analog baseband bandwidth requirement above 5 MHz. If practical coding techniques are used, the digital video signal, in addition to its ability to permit complete regeneration, will have a greater immunity to noise than the analog signal

Microwave Radio Systems for Video

Common carriers are restricted to certain frequency bands in the microwave spectrum. The bands available are in the 2-, 4-, 6- and 11 GHz portions of the spectrum. Individual communication channels in the 2 GHz bands are only 800 kHz wide, too narrow for the types of video mentioned previously. At 4 GHz the rf channels are 20 MHz wide and are used extensively for broadcast television. The rf channels in the 6 GHz band are approximately 30 MHz wide, while those at 11 GHz are 50 MHz wide The importance of the microwave channel rf bandwidth, at this point, is that the rf channel bandwidth directly controls the baseband bandwidth available for the video signal The common carrier bands most often used for analog transmission of video are at 4 and 6 GHz

The analog video bandwidth requirements are easily satisfied by a possible 7 5 MHz baseband at 4 GHz and 12 MHz at 6 GHz using frequency or phase modulation Digitized video involves bit rates that require much greater bandwidth, however, and this bandwidth requirement is a major problem in digitized video transmission Digitized black and white television at a 45 megabit rate would require a minimum of 22 5 MHz baseband bandwidth if it were transmitted using binary PCM at the "Nyquist Rate."

To find a satisfactory method of transmitting a digitized color video signal over a microwave system, for medium and long distances, becomes mainly a problem of fitting the digital information into the baseband of the microwave system. The 6 GHz band has the widest baseband of those acceptable for long distance microwave transmission. The 11 GHz band is wider but may have transmission problems when these frequencies are severely attenuated by rain

The 6 GHz microwave system is preferred for long distance digital transmission. For example, a typical modern 6 GHz heterodyne repeater microwave system, has a flat amplitude and group delay response across the baseband of 12 MHz The stations may be assumed to be spaced 27 miles apart and have the following system characteristics.

Output Power	+10 dbW
Antenna Gain 2(43 db)	86 db
Avg. Path Loss (Median)	141 db
Waveguide Losses	10 db
Single Path Received Signal	−55 dbW
Noise Figure	6 db

The single path, $S_{p\text{-}p}$, peak to-peak signal-to-rms noise, N_{rms}, ratio, for a peak deviation of 2 MHz and a 12 MHz baseband bandwidth would then be

$$\frac{S_{p\text{-}p}}{N_{rms}} = \frac{3C}{KTFB} \times \frac{(2D)^2}{F_m}$$

where C — carrier power
D — peak deviation
F_m — highest modulating frequency
KT — thermal noise power per cycle at 20°C
F — noise figure of receiver
B — baseband bandwidth

$$\frac{S_{p\text{-}p}}{N_{rms}} = 10 \log C - 10 \log KT - 10 \log F$$

$$- 10 \log B + 10 \log 3 + 20 \log \frac{2D}{F_m}$$

substituting the values above

$$\frac{S_{p\text{-}p}}{N_{rms}} = -55 + 204 - 6 - 71 + 4.8 - 9.5$$

$$\frac{S_{p\text{-}p}}{N_{rms}} = 67.3 \text{ db}$$

Since this is the signal-to-noise ratio for a single path of a heterodyne repeater microwave system, then the noise contribution for eight paths in tandem is eight times that of one path or 9 db greater. The median peak-to-peak signal-to-rms noise ratio is then approximately 58 db for this 8-hop hypothetical system. The effect of adding eight sets of filter characteristics on the baseband bandwidth and delay is small because the microwave frequency filters are very wide and flat and they do not restrict the baseband bandwidth beyond the limits of practical delay correction. Confining baseband filters are required only when the system is demodulated. They appear only at the terminations of a modulation section, whether it be one or eight hops. The 12 MHz baseband bandwidth and 2 MHz deviation, selected as systems parameters, are chosen so that the special distribution of microwave energy does not exceed the FCC constraint that no more than 1 percent of the radiated energy appear outside of the maximum 30 MHz bandwidth allocated for the 6 GHz Common Carrier Band. "Carson's Rule," ($Bw = 2 F_m + 2 D$), gives a rough estimate to the 99 percent power bandwidth of the modulated spectrum. Any increase in the highest modulating frequency drastically reduces the permitted deviation and the effective signal-to-noise ratio.

This heterodyne repeater microwave system, using PCM at the Nyquist rate, has a maximum capability of 24 megabauds. Baseband filters require a carefully controlled "roll-off" to achieve this optimum signaling rate. Earlier it was established that black-and-white television, without the addition of a digitized program sound channel, requires approximately 45 megabits/sec capability. If binary PCM were used, the equivalent system capability would be 24 megabits/second and would require a baseband signal-to-noise ratio of 14.4 db to achieve a theoretical error rate of 10^{-4}. A quaternary system would double the bit rate to 48 megabits/second, with a required $S_{p\text{-}p}/N_{rms}$ of 21.3 db. An 8 level system would permit further increase in the bit rate to 72 megabits/second and still have a seemingly acceptable signal-to-noise ratio requirement of 27.6 in comparison to the 58 db eight-hop median signal microwave performance. There is another consideration, however. The S/N required for the 10^{-4} error rate is predicated on a received signal that is not distorted by the transmission system in any way that will make the level of the received pulse at the sampling point a function of the preceding or succeeding pulses. In practice, this ideal involves precise control of the transmission bandwidth in amplitude roll off and flat delay. Failure to achieve this ideal distorts the signal in a way that causes interference between successive pulses referred to as intersymbol interference. Although this interference does not necessarily make it impossible to resolve the signal without error, it reduces the margin of level decisions and, consequently, makes the system more sensitive to noise.

If we assume that the system has 10 percent intersymbol interference, or that

the level of any pulse at the sampling point could be changed by 10 percent of the peak pulse amplitude by the interference of other pulses, then the interference represents 20 percent of the margin for decision in the binary case and 60 percent in the quaternary. Interference in the octernary case exceeds the margin, producing significant errors even in the absence of noise. This makes the eight level system completely unacceptable, if the actual intersymbol interference approaches 10 percent. The quaternary code represents the best compromise in this case because it provides twice the binary capacity and can take advantage of the low noise characteristics of the microwave system to deliver a reliable signal with an extremely low error rate.

Compression of the Video Signal

With the 48 megabit capability of this microwave system, using quaternary PCM, there would be space for digitized black and white television and its program channel. However, if we eliminate some of the natural redundancy of the video channel, we can compress the video information into fewer bits, and be able to transmit the necessary added information for color within the 48 megabit/second capacity.

Many schemes have been devised for compressing the video bit requirement and each seems to have particular advantages and disadvantages. The simplest way would be to decrease the number of line samples. This would reduce the required digital capacity in nearly direct proportion to the change in the number of samples, but would produce a detectable loss in horizontal resolution. Another method might be to reduce the frame rate, which would also proportionately reduce the bit rate requirement. Although this would preserve the resolution, it would not present motion smoothly.

One of the methods most likely to be accepted is "Delta Modulation." The method is named from the fact that it transmits the difference, or change in level, between successive samples, rather than their absolute value. Since the usual luminance changes along a scanning line are gradual for the largest percentage of the time, the change between successive samples is usually small and can be represented by fewer than the 6 bits contemplated earlier. If we use 4 bits instead of 6, the bit requirement is reduced by ⅓ without losing resolution or affecting the response to motion. There can be some difficulty if abrupt large changes in luminance force the 4-bit delta system beyond its range of ± 8 (1/64) levels. It will take 4 (⅛) changes to indicate a step change of ½ the luminance range. Some smearing along vertical edges will be evident. This effect can be reduced by assigning an exponential, rather than linear, distribution to the 8 levels. As an example, the 4 bits of information of each sample represent the following level changes from the previous sample:

1st bit — positive or negative luminance change

2nd, 3rd, 4th bit — represents 8 levels of the luminance range

Level 1 = 0
Level 2 = 1/64
Level 3 = 1/32
Level 4 = 1/14
Level 5 = ⅛
Level 6 = ¼
Level 7 = ½
Level 8 = 1

Successful reproduction obviously depends on the picture to be transmitted. The picture quality using compressed delta modulation can be as good as 6-bit 64-level coding with ⅓ less spectral requirement.

With a type of acceptable compression, the microwave digital capacity can be utilized to carry the chrominance information and, possibly, additional data that can be time division multiplexed with the video. A system operating within the described parameters can carry color video plus some additional amount of data which may be required for special applications.

Reliability

The reliability of a microwave system, in terms of the PCM error rate obtainable, can be estimated once the fading characteristics of the system have been established

To predict the propagation reliability, the relationship between baseband noise and error rate must be established. The baseband noise is inversely proportional to the received microwave signal level, as long as the received signal is above threshold With median received signals of –55 dbW and 30 MHz receiver noise levels of –124 dbW, a fade of 59 db is required to reach threshold at a C/N of 10 db. As shown Figure 1, a fade of 6 db to a received signal level of –101 dbW produces an unacceptable error rate. It is evident that threshold lies below the levels required for this analysis. Thus, the system fading character can be utilized to determine the reliability of a microwave system at specific error rates.

Figure 1 is a curve of the error rate in a practical quaternary PCM system in relation to the peak to-peak signal to rms noise ratio in the baseband and, also, in terms of the received signal level of a microwave receiver with a 6 db noise figure and a 12 MHz baseband bandwidth. The curve assumes some intersymbol interference and equipment instability. It is obvious that the 67 db peak-to-peak signal to rms noise ratio for a single hop and the 58 db for the 8 hop system are far better than the 27 6 db required for a low 10^{-7} error rate. These figures indicate the conditions that exist under median signal reception; that is, they are exceeded for 50 percent of the time

To calculate the reliability of the system to fading of the received signal due to atmospheric conditions, it is necessary to obtain the propagation characteristics of the paths concerned The fading characteristics should be given in terms of the cumulative probability of fades below specific depths. If it is assumed that all paths in the 8-hop hypothetical section have Raleigh distributed fading, the system reliability can be calculated from the curve

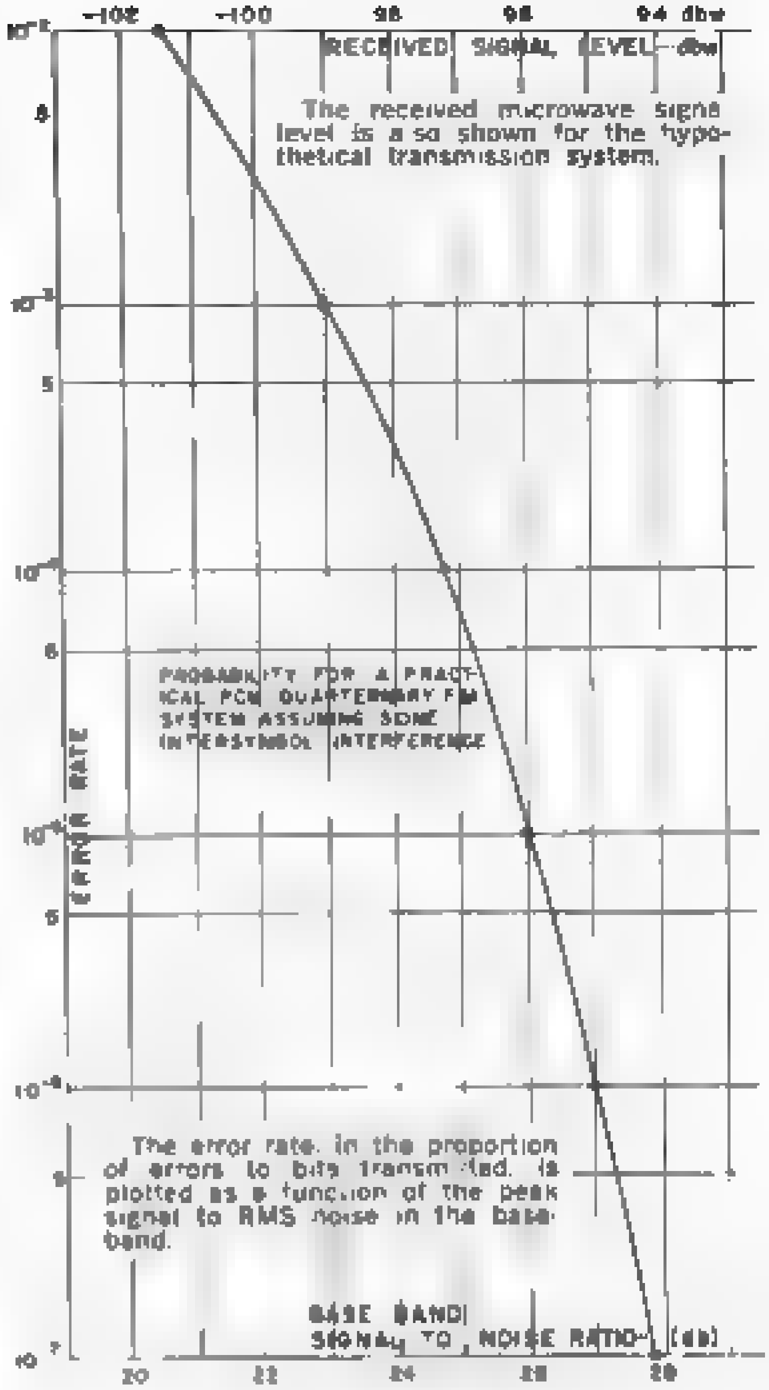


Figure 1 — Error Rate for a Quaternary PCM System

shown in Figure 2. Using Figure 1 to determine that an error rate of 10^{-5} requires a received signal level of –96 dbW and subtracting that level from the established median received signal level of –55 dbW, shows that a fade of 41 db must occur before the error rate degrades to 10^{-5}. From the Raleigh distribution curve each path would have a probability of being less than 41 db down from median signal for 99.995 percent of the time or of being below 41 db for 0.005 percent of the time Since this is such a small part of the time, it can be assumed that, in 8 hops, the probability that any one hop would be faded below 41 db is eight times as great

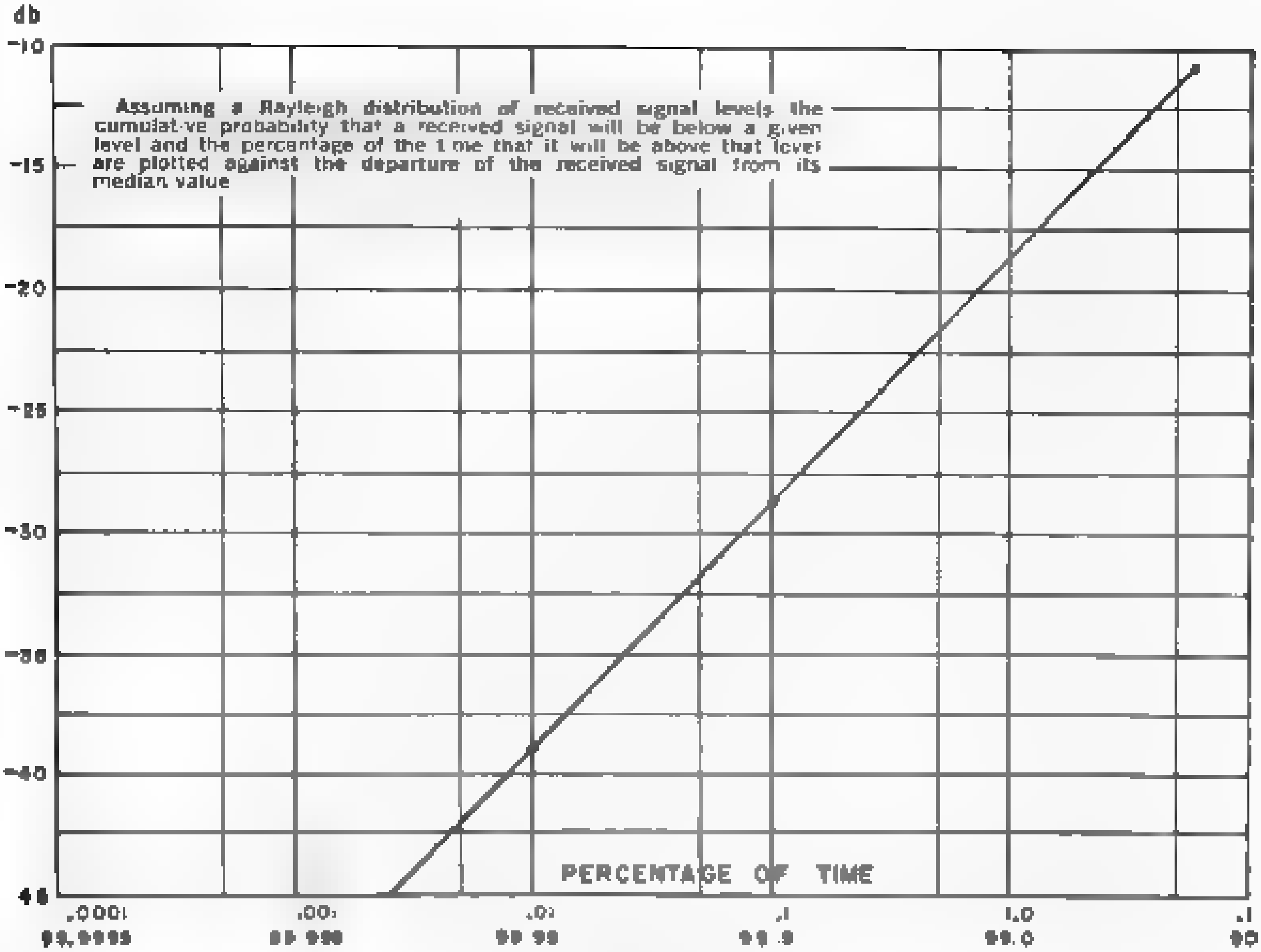


Figure 2 — Rayleigh Distribution

or 8 (.00005) = .0004. The system would then be operating with a probability that for 99.96 percent of the time the error rate would be 10^{-5} or better. The reliability can be obtained similarly for any other error rate

The reliability described is for a single tandem 8 hop system. It can be improved substantially by doubling the microwave facility and utilizing a 1 for 1 diversity arrangement. Ideally, if two separate non-correlated systems are used to carry the same information; and, if a switch is used to select the non-faded system, the probability of the selected signal fading below 41 db is the probability of the signals fading simultaneously below 41 db. This probability is the product of the outage times, .0004 × .0004 = .00000016, or a probability that for 99.999984 percent of the time the error rate would be better than 10^{-5}. This is exceptionally good reliability and contemplates only outages due to propagation conditions. In a practical case, the equipment reliability will become an important factor restricting the overall reliability.

Potential

A system such as this is obviously useful at distances much greater than the 8 hops of the hypothetical section. Sections can be designed to operate in tandem in a transcontinental system. If the signal were regenerated at each demodulation point, every 8 hops, the total time the error rate exceeded 10^{-5} would be a direct function of the number of sections. If the signal were not regenerated, the intersymbol interference and noise would accumulate and the outage time would increase exponentially with the number of tandem sections.

Such a system would be a natural extension of the digitized video transmission facilities Western Union is presently providing for the Government ■

Anniversaries
Committee on Technical Publication
Technical Publications

Committee on Technical Publication: On Our 20th Anniversary — We Resolve

Western Union TECHNICAL REVIEW, Vol. 21, No. 3 (August 1967) pp. 126 to 127

The Committee on Technical Publication has had the responsibility of reviewing all articles published in the TECHNICAL REVIEW since its inception in July 1947. Mr. C. G. Smith, a member of the Committee, has had the longest tenure of representation on the present Committee because of his advisory capability. He has been asked by the Chairman, Mr. Warren Fisher to formulate a resolution at this time.

This article publishes photos of previous Committees and also the first Chairman of the Committee on Technical Publication Mr. P. J. Howe, who is responsible for launching the TECHNICAL REVIEW.

Digital Transmission
Microwave Radio
Satellite Communications

Mueller, E. H., Liu, D. J. and Sheldon, M.: Analog and Digital Transmission over Microwave Systems

Western Union TECHNICAL REVIEW, Vol. 21, No. 3 (August 1967) pp. 130 to 138

The advantages and disadvantages of analog and digital transmission over microwave systems are reviewed in this article.

The transmission characteristics of microwave systems are manifested in the baseband, but are the result of noise and distortion contributed from all parts of the system. The type of noise and distortions are described and the equations for calculating their magnitude are indicated.

The trend to use digital microwave transmission for satellite communication systems makes the analysis of microwave digital capability even more important to Western Union at this time.

Microwave Radio
Transmission Systems
Digitized Video Transmission

Greenquist, R. E.: Microwave Radio— the Backbone of W. U. Transmission Systems

Western Union TECHNICAL REVIEW, Vol. 21, No. 3 (August 1967) pp. 128 to 129

This article points out the comparison of the capacity of Western Union's microwave system proposed in 1947 with the capacity of its microwave radio systems today.

The author emphasizes that microwave radio in 1947 served only a small section of the United States and land line carrier was the basic transmission facility, while today microwave radio spans the continent as the backbone of Western Union's communication plant.

Announcements
Terminal Equipment
New Products

[illegible]

Western Union TECHNICAL REVIEW, Vol. 20, No. 3 (August, 1967) pp. 139

The INFO Terminal 311 is a new unit designed for high speed communication to service 5 and 8 level chad tapes interchangeably.

This announcement points out the special features as well as the optional features of the unit.

THESE ABSTRACT CARDS MAY BE CUT OUT AND PASTED ON LIBRARY CARDS FOR FILING

SERVICE TO OUR READERS: As a service to our readers, articles will be abstracted so that a complete file may be kept for reference purposes.

Ottenberg, E. C., Mac Michael, G. R. and Johnston, G. W.: Satellite Earth Stations

Western Union TECHNICAL REVIEW, Vol. 21, No. 3 (August 1967) pp. 140 to 153

This article illustrates the effect of technical and economic factors on the design of common carrier earth stations within the existing regulatory framework. Western Union has investigated a method of predicting the performance of a particular satellite system using the constraints imposed by the Federal Communication Commission.

Calculations of a hypothetical system were made to illustrate this approach.

Solid-State Equipment
Tributary Systems
Microwave Radio Systems
New Products

Klimek, D. D.: NSD-6 Radio System

Western Union TECHNICAL REVIEW, Vol. 21, No. 3 (August 1967) pp. 154 to 161

A modern all solid-state microwave radio relay equipment has been developed by Western Union for low cost, short-haul, low density tributary systems. This article describes the NSD-6 radio equipment named for the Narrow Bandwidth, Short Distance-6 GHz operation it suggests.

An important advantage of the NSD-6 radio system is that it requires only minimal support facilities for a remote installation. It is light in weight, small in size, consumes low primary power and operates over a temperature range of —30°C to +60°C. It has a capacity of 360 voice channels and its noise performance for one hop is equivalent to that required by the CCIR for a 10-hop trunk system.

Digital Transmission
Microwave Radio
Television
Information Systems

Mueller, Edwin H.: Digitized Video Transmission over Microwave Radio

Western Union TECHNICAL REVIEW, Vol. 21, No. 3 (August 1967) pp. 162 to 167

When microwave radio systems are the medium of transmission, television (video) picture quality is degraded by the length of the system and the atmospheric condition along the route. Digital transmission can improve this condition because digital signals can be regenerated periodically, thus permitting long distance transmission without deterioration due to additive noise.

This article describes the digital video signal and a satisfactory method of transmitting it over a microwave system for medium and long distances. This method is related to fitting the digital information into the baseband of the microwave system.

Editorials
New Subscription Rates

Killilea, Mary C.: Looking Ahead with the TECHNICAL REVIEW

Western Union TECHNICAL REVIEW, Vol. 21, No. 3 (August 1967) pp. 170 to 172

This editorial by the Editor of the Western Union TECHNICAL REVIEW points up the future articles to be published as compared with those in the first issue of this publication.

The article emphasizes that Western Union is ahead of its day in the engineering know-how it displays in the publication.

On the 20th Anniversary of the TECHNICAL REVIEW, new publication dates, new subscription dates, new editorial offices are announced.

looking ahead

with the

Technical Review

MARY C. KILLILEA

It has been my special privilege to edit and help publish the articles written by our engineers at Western Union for five of the twenty years we celebrate today.

As I review the many issues of our technical publication, it is rewarding to find we have successfully carried out the objectives set forth in the first issue, Volume 1, Number 1, published in July, 1947. The Foreword on page one of that issue reads:

FOREWORD

This, the first issue of the Western Union TECHNICAL REVIEW, inaugurates a project by which it is hoped that technically minded employees may become better informed regarding some of the fundamentals which underlie the technological progress of their Company.

Science and its practical application have revolutionized ways of living since Morse blazed the trail with his telegraph. In present day life, the needs of the public and competition force industry to search constantly for new ways and new products, and to utilize the latest results of scientific skill. Long ago the telegraph industry discarded the Morse key and sounder — its early symbol of distinction — to make way for modern methods.

Mechanization is synonymous with progress. Electronics, facsimile and microwave radio have become commonplace in Western Union language and thinking. Changes in methods and facilities are taking place rapidly — so rapidly that there is need for a new medium to give the Company's personnel a better understanding of the tools now being placed in use, and a better ability to use these tools easily and effectively.

This TECHNICAL REVIEW is primarily intended for employees who are concerned with the installation, maintenance or operation of technical equipment. The publication will be issued quarterly and at first will constitute a medium for distributing reprints of technical papers which have been presented before engineering or scientific societies or published in established periodicals. Later it is planned to include specially written technical articles, and it is hoped that field employees as well as headquarters engineers will be counted among the authors.

The Committee on Technical Publication, which will issue this periodical, will welcome comments and suggestions that may be helpful in the planning of future issues.

In the second issue, Volume 1, Number 2, 1947, we are aware that the pioneers of our publication, the Committee on Technical Publication, so ably directed by Mr. P. J. Howe, Chairman, had unusual vision when they published such articles as, "Carrier Terminals Without Relays," by F. H. Cusack and A. E. Michon. The Foreword of that second issue reads: "This article by Cusack and Michon is ahead of its day, in that it describes a development of apparatus which has yet to be widely distributed throughout the field." This issue was another step forward toward the objective of informing Western Union employees of the scientific thinking and progress of their Company. It may serve our new employees well to read the first two issues of the TECHNICAL REVIEW and share in the pride and heritage we have in our technical publication.

From my observation and experience with our engineers today, I believe the articles in this issue, our 20th Anniversary issue, are still ahead of their day. They are basic to our understanding of Satellite Communications—a future Western Union anticipates. The article entitled, "Digitized Video Transmission Over Microwave Radio," reveals the possibilities of Western Union in modern video transmission of analog and digital information. The article on, "Satellite Earth Stations," describes a method of predicting satellite system performance as related to Earth Station design. The article on "Analog and Digital Transmission over Microwave Systems" brings us up to date on the current trend to use digital microwave transmission for satellite communications systems.

In the past five years, the TECHNICAL REVIEW has grown from a circulation of 7,000 to a circulation of 12,000 copies. The size of the magazine has increased from 36 pages to 64 and 72 page issues. The Special Telex Issue, July 1966, concentrated 64 pages of technical copy on documenting the engineering know-how, responsible for one of Western Union's most successful public message services — Telex. The 72 page issue of January, 1967, published the many new developments in Circuit Switching and Message Switching for G. S. A., AUTODIN, and Telex. The Government Communication Systems Issue of January, 1966 emphasized Western Union's service to the Government.

The TECHNICAL REVIEW is considered the only publication devoted exclusively to record communications. Recently, it has been documenting the developments at Western Union in data processing, which involves record communications. On-Line data processing is particularly concerned with record communications. Future issues of our technical publication are planned in this area.

Letters to the Editor from our field employees emphasize the fact that the TECHNICAL REVIEW serves a great information need to those technical minded employees who are constantly striving to keep abreast the new developments of our Company. Letters to the Editor from paid subscribers in 19 countries outside the United States indicate our publication has world-wide appeal. Letters to the Editor from Government Agencies prove our TECHNICAL REVIEW is helping to educate our customers as well as our own employees.

The future issues on our present editorial schedule reinforce my sincere conviction we are *"looking ahead"* with the TECHNICAL REVIEW in inspiring the technical minded employees of Our Company with the tremendous technical capability of our engineer-authors.

As Editor of the Western Union TECHNICAL REVIEW, it has been a great personal challenge to me to be part of these twenty years. I should like to re-emphasize the request of the Committee on Technical Publication in their first issue which stated, "We will welcome comments and suggestions that may be helpful in planning future issues."

We hope to expand our publication — because our new employees have greater and greater need for a media of documenting their engineering progress in telecommunications at Western Union.

ANNOUNCEMENTS

- *New Publication Dates*

  Starting with this issue the TECHNICAL REVIEW will be published in February, May, August and November.

- *New Editorial Offices*

  The Office of the Editor has moved from 60 Hudson Street, New York City to 82 McKee Drive, Mahwah, New Jersey

- *New 20-Year Index*

  The 20-Year Index of Titles and Authors of articles published in the TECHNICAL REVIEW from July, 1947 thru April, 1967 is available by request.